Windrow Composting Engineering/Economic Evaluation

Report No. CETHA-TS-CR-93050
Contract No. DACA31-91-R-0009
Task Order No. 01

May 1993

Prepared for:
U.S. Army Environmental Center (USAEC)
CET-HA-TD-5
Aberdeen Proving Ground, MD 21010-5401

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EXECUTIVE SUMMARY

A conceptual level development of the use of composting technology for the treatment of explosives-contaminated soils and sediments has been conducted. These soils and sediments exist at a variety of Army ammunition plants (AAPs) and Army depots (ADs) as a result of post-industrial activities associated with the production of munitions. Previous investigations of the technical aspects of explosives composting, including recent U.S. Army Environmental Center (USAEC) field demonstrations, have shown composting can significantly reduce explosives levels in contaminated soils.

This report presents a conceptual level facility design, including construction and operating requirements, and an economic evaluation for a windrow composting facility. All equipment specifically named by the vendor is for illustrative purposes. Equivalent equipment could be used. This design reflects the current level of technology with respect to both technical and regulatory aspects. Brief system descriptions and costs are also presented for aerated static pile and mechanically agitated in-vessel composting technologies.

Table ES-1 presents "treatment only" costs for windrow, aerated static pile, and mechanical in-vessel composting systems as well as incineration. This table does not include costs associated with soil excavation or final compost disposal.

All three composting technologies exhibit the potential for cost savings compared to incineration. Although all three composting systems have demonstrated explosives reduction in field demonstrations [4,5], windrow composting has shown the greatest reductions in TNT, RDX, and HMX. Based on explosives reduction and economic considerations, windrow composting is the most viable treatment approach. Based upon the present state of technology, a windrow composting facility could be designed and operated using previously demonstrated operating parameters.

Although all required research and development activities related to windrow implementation have been completed, there are several areas that could be optimized with further testing. These areas include increasing the compost soil loading, decreasing the compost cycle time, and eliminating compliance to RCRA minimum technology standards.

Table ES-1

Estimated "Treatment Only"[a] Project Costs for Composting and Incineration

Technology	Capital Cost ($)[b]	Annual O&M Cost ($)	5-Year O&M Cost ($)	Total Project Cost ($)	Cost per Ton ($)[c]
Windrow Composting	1,891,000	464,000	1,853,000	3,744,000	187
Aerated Static Pile Composting	1,966,000	692,000	2,763,000	4,729,000	236
MAIV Composting	3,294,000	628,000	2,507,000	5,801,000	290
Incineration	2,000,000[d]	u[e]	4,000,000[f]	6,000,000	300

[a]Costs do not include excavation and final disposal.
[b]Based on 20,000 tons of soil processed over 5 years.
[c]Does not include salvage values of equipment.
[d]Mobilization/Demobilization only.
[e]Annual costs are not determined; 5-year total based upon net cost per ton is provided.
[f]Based on 20,000 tons of soil @ $200/ton.

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A conceptual level development of the use of composting technology for the treatment of explosives-contaminated soils and sediments has been conducted. These soils and sediments occur at a variety of Army ammunition plants (AAPs) and Army depots (ADs) as a result of post-industrial activities associated with munitions production. Previous investigations, including recent USAEC field demonstrations, have shown that composting can significantly reduce explosives levels in contaminated soils.

This report presents a conceptual level facility design, including construction and operating requirements, and an economic evaluation for a windrow composting facility. System descriptions and costs are also presented for aerated static pile and mechanically agitated in-vessel composting technologies. All three composting technologies demonstrated cost savings versus incineration for comparable remedial project sizes.

The "treatment only" windrow composting cost for treatment of 20,000 tons of explosives-contaminated soil in a 5 year period was estimated to be $187 per ton of soil. An economic sensitivity analysis was conducted to determine the effect of project duration (1, 3, 5, 8, and 10 year periods for 20,000 tons of soil) and facility size (2,000, 5,000, and 10,000 tons of soil processed in 2 years). It was found that increasing treatment period beyond 3 years offered little economic benefit.

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SECTION 1

INTRODUCTION

1.1 PROBLEM STATEMENT

The contamination of soils and sediments at Army ammunition plants (AAPs) and Army depots (ADs) has occurred in areas where explosives and propellants were produced and handled. One source of explosives-contaminated soils is lagoons and sedimentation basins used to settle out the explosives from explosives manufacturing and washout operations. These practices resulted in contamination of sediments with various explosives, including 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and n-methyl-n-2,4,6-tetranitroaniline (tetryl).

Soils and sediments contaminated with explosives may require treatment to prevent possible contaminant migration. Several treatment technologies have been investigated by the U.S. Army Environmental Center (USAEC, formerly known as the U.S. Army Toxic and Hazardous Materials Agency or USATHAMA) for possible application during remediation of soils and sediments contaminated with explosives.

One potential treatment technology for explosives and propellant-contaminated material is composting. There are several potential advantages associated with composting, which may encourage its development as a remedial technology. It generally requires a relatively low level of manpower and energy for operation and, therefore, may prove an economical alternative to other destructive treatment technologies. Furthermore, emissions from the process are relatively minimal (so long as odors and leachate are controlled) and the product (i.e., finished compost) is aesthetically acceptable.

The primary historical use for composting technology has been the treatment of municipal solid wastes, agricultural wastes, and wastewater treatment plant sludges. However, more recent interest has developed in its potential use for treatment of industrial wastes.

Previously, USAEC has conducted several pilot-scale composting studies to evaluate this technology for explosives-contaminated soils and sediments. The Louisiana Army Ammunition Plant (LAAP) field test demonstrated that aerated static pile composting of explosives-contaminated soil at a field-scale is technically feasible. This study also compared mesophilic and thermophilic (55 °C) composting conditions and concluded that higher biotransformation rates for explosives were achieved under thermophilic conditions than under mesophilic conditions [1].

The Badger Army Ammunition Plant (BAAP) field test demonstrated the technical feasibility of aerated static pile composting of nitrocellulose [2]. Based upon these field demonstration projects, USAEC conducted a composting technology development project to evaluate full-scale implementation options and to develop conceptual level

engineering and cost information [3]. The composting technology development presented a design approach and economic analysis for aerated static pile and mechanically agitated in-vessel (MAIV) composting. The technology development study concluded that composting could become an economically attractive treatment option for explosives-contaminated soils, and that optimization of several process parameters was needed to achieve that promise. This study developed optimization parameters based on the projected process economics.

The optimization parameters developed in the composting technology development were tested and validated in a compost optimization field test at the Umatilla Army Depot Activity (UMDA) [4]. The UMDA optimization study tested and validated the optimization parameters recommended in the technology development study, resulting in substantial improvements in process performance and projected economics. Both aerated static pile and MAIV systems were tested. A subsequent optimization study at UMDA examined the potential benefits of compost recycling, and provided the first test of the windrow method of composting for explosives-contaminated soils [5]. This test demonstrated the feasibility of windrow composting and evaluated alternative windrow operating strategies.

The purpose of the present study is to evaluate possible system configurations for full-scale implementation of windrow composting as a remedial technology. This evaluation will be based upon the previous technology development study [3] and the subsequent composting optimization projects at UMDA [4,5].

1.2 OBJECTIVES OF STUDY

The objective of this project is to develop, at the conceptual level, a system or approach for windrow composting of explosives-contaminated soils at Army facilities. The windrow technology will be compared to aerated static pile and mechanically agitated in vessel technologies evaluated in previous studies [3]. The information resulting from this effort will be used both in planning full-scale implementation and in evaluating the need for additional process development and optimization.

To accomplish these objectives, several tasks were required:

- A brief review of recent literature on the potential application for windrow composting of industrial wastes and on composting parameter optimization.
- Consideration of potential regulatory requirements for explosives-composting operations.
- Development of conceptual level windrow facility descriptions, including process flow diagrams and materials balances, conceptual facility layouts, and operating requirements.

- Development of general construction requirements and major equipment lists.

- Conceptual level economic analysis, including capital cost estimates, and operating and maintenance (O&M) cost estimates.

- Economic sensitivity evaluation to determine the effect of treatment duration on process economics.

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SECTION 2

BACKGROUND INFORMATION

2.1 REVIEW OF COMPOSTING TECHNOLOGIES

Composting is a process by which organic materials are biodegraded by microorganisms under controlled conditions. Microbial activity results in the production of organic and/or inorganic byproducts and energy in the form of heat. Traditionally, composting has been considered to occur under aerobic, thermophilic conditions (temperatures in the range of 55 to 60 °C) [6]. Recent applications of composting technology to industrial wastes have broadened the definition to include possible mesophilic as well as thermophilic conditions [3, 18]. Disposal of organic wastes under conditions now called composting has been practiced for many years. The advent of composting as an engineered (i.e., controlled) process is more recent, with most interest in the composting of municipal and industrial sludges in the United States dating to the early 1970s [7].

Composting can be initiated by mixing biodegradable organic matter with bulking agents and, possibly, other amendments. In conventional composting systems, the bulking agents are added primarily to enhance the porosity of the mixture to be composted, but may also provide additional carbonaceous substrate for the microorganisms. As demonstrated in USAEC's previous work, materials of relatively low total organic content, such as contaminated soils, may be composted through the addition of other high organic carbon sources. In such cases, the added organic carbon fraction, in addition to being degraded or stabilized itself, serves to maintain the necessary microbial population in the compost mixture and to support the development of thermophilic conditions.

Several parameters have been shown to be important in the design and operation of conventional composting systems:

- Compost temperature.
- Compost oxygen content.
- Compost moisture content.
- Compost pH.
- Type and concentration of organic constituents.
- Concentration of inorganic nutrients, such as nitrogen and phosphorus.

The primary control parameters for conventional aerobic, thermophilic composting are temperature and oxygen, both typically controlled by the use of various aeration or ventilation strategies. At least in part, this emphasis has resulted from the defined goals of municipal waste composting, which include pathogen reduction by maintenance of elevated temperatures and odor control by aeration (to prevent anaerobic conditions in the compost). The remaining parameters are largely controlled by the formulation of the compost mixture itself.

Conventional composting is typically implemented at one of three general levels of technology. These levels differ in the degree of manipulation required and the level of process control achieved. As would be expected, costs generally increase with increasing technology level. At the lowest technological level, the material to be composted is shaped into a pile and allowed to self-heat. If needed, water and nutrients may be added. At this level, air exchange is relatively poor, and temperatures may fluctuate within the composting material; however, aeration and homogeneity may be increased by periodically turning and mixing the pile with mechanical equipment. This level of technology is referred to as a "windrow" system because of the long rows of narrow compost piles typically employed.

At the next technological level, an aeration/heat removal system is used to increase process control over the composting system. The aeration/heat removal system typically takes the form of a network of perforated pipe underlying the compost pile. The pipe is attached to a mechanical blower, and air is periodically blown or drawn through the pile. This composting configuration is often referred to as "aerated static pile." While this approach provides higher control of aeration and heat removal, the lack of mixing may reduce the homogeneity of the compost mixture. Windrow configurations may also be modified to include aeration piping, thus increasing the degree of process control achievable.

At the highest technological level, a system of enclosed composting vessels and automated materials handling and mixing equipment is used in conjunction with an aeration/heat removal system. This type of system is known as "mechanical" or "in-vessel" composting. Potential advantages often cited for mechanical composting include more rapid or complete waste stabilization and improved aesthetics because the compost material is largely contained in the reactor system; however, these potential advantages, where achieved, may entail substantially higher capital and operating costs.

While these generalities regarding technology levels are useful rules of thumb, they must be used with caution. For example, static pile composting can be conducted in vessels or bins or in windrows. Windrows without instruments and blower-controlled temperature regulation may be maintained within relatively narrow operating parameters by the use of frequent turning based upon process monitoring. Furthermore, the cited advantages of in-vessel composting are not always fully realized. As with any environmental engineering treatment process, selection among the alternative technical approaches should be based upon a case-specific definition of treatment goals and constraints, process parameters to meet those goals, and process economics.

Composting is widely used to stabilize wastewater sludges and municipal refuse in the United States and Europe [7]. The primary objectives of refuse/sludge composting are to:

- Reduce the volume of waste or sludge.
- Reduce the moisture content of the composting material.

- Destroy potentially odorous nitrogen and sulfur-containing organic compounds.

- Destroy pathogenic microorganisms.

- Stabilize the compost material for ultimate disposal.

Operating experience has shown that these goals are met by maintaining aerobic, thermophilic conditions within the compost matrix. In fact, the regulatory definition of composting as a process to reduce pathogens in sludge include maintenance of temperatures in excess of 55 °C for three consecutive days [18]. Many sludge composting processes employ this as a primary criterion, with additional treatment as needed to achieve the remaining process goals.

Because sludge and refuse are generated continuously, these objectives are best met by a composting system designed for relatively rapid turnover of incoming wastes. The rate of waste treatment and disposal must approximate the rate of waste generation for wastewater and refuse facilities to operate efficiently.

In contrast, the primary objective of hazardous materials composting is to convert specific hazardous substances into innocuous products for ultimate disposal. Rapid processing is desirable but remains secondary to successful treatment of the contaminants. Thus, while hazardous materials composting systems share many of the characteristics of sludge and refuse composting systems, operational parameters will differ according to the primary objective of the process.

Composting is a combination of biological and engineering processes. Biological aspects of the process that require management include optimizing the environmental conditions required to enhance microbial growth and to maximize contaminant destruction within the compost pile. Engineering aspects that require attention include materials handling, composting facility design and operation, and process control systems. Both biological and engineering requirements must be addressed in order to provide a cost-effective and successful treatment process.

2.2 EXPLOSIVES COMPOSTING TECHNOLOGY

Previous studies have demonstrated the susceptibility of explosives and propellants to microbial transformation or degradation [1,2,4,5]. Routes of bioconversion, intermediates, products, and analytical methods to assess the results have been largely determined [1,4]. Field demonstrations of composting explosives-contaminated (TNT, HMX, and RDX) and propellant-contaminated (NC) soils at LAAP, BAAP, and UMDA [1,2,4] were successful in terms of reducing explosive concentrations through biotransformation, as well as achieving required soil loading levels and reducing amendment costs to ensure the economic viability of composting. Composting of these energetic compounds has been conducted on a pilot scale in reactor vessels and in windrows sufficiently large to simulate field conditions. For nitroaromatic explosives, biotransformation to organic end products, rather than mineralization to carbon

dioxide, is achieved. Additional testing has demonstrated that the endproducts are bound in a nonextractable (nonleachable) form in the compost matrix and that substantial reduction in toxicity is achieved in the process [17]. As such, composting of explosives-contaminated soils and sediments may achieve the general goals of reduction in toxicity and mobility for hazardous wastes under the Superfund Amendments and Reauthorization Act of 1981 (SARA).

2.3 KINETICS AND REACTION PARAMETERS

Because the design of a composting facility is strongly dependent on the kinetics of the specific transformations that are being accomplished, data from past explosives-composting studies will be used to estimate the size of various composting facility configurations.

The pilot-scale experiments reported in the Atlantic Research Corporation study [12] and the UMDA field demonstration conducted for USAEC by Roy F. Weston, Inc. (WESTON®) [4] determined that, in some cases, the rate of disappearance of the target explosives may be approximately described by first order reaction kinetics (i.e., a rate equation of the form $C = C_0e^{-kt}$ where C is the concentration at time t, C_o the concentration at time 0, and k the specific rate constant).

Under first order kinetics, the half life of the constituent, or the time required for half of the existing quantity of concentration to degrade, is constant. In many cases, however, first order kinetics did not provide an adequate description of the observed explosives removal data. The kinetic relationships governing explosives transformation in compost systems have not been defined. For purposes of this study, empirical observation of required treatment periods from previous tests will be used for purposes of process evaluation. Although the calculated kinetic parameters may not precisely predict concentration values over the entire composting period, they do represent a reasonable approximation and are a good tool for comparison among composting systems. It should also be noted that in some cases an apparent lag phase occurs before explosives transformation begins. The length of this apparent lag phase must also be considered in evaluating required treatment times.

Table 2-1 summarizes the experimental conditions from which kinetic data were obtained in each study, as well as the first order rate constants and half-lives estimated for each constituent.

Given the range of operating conditions in these experiments, the kinetic data obtained appear to be reasonably consistent. It should be recognized that the effects of explosives concentration, interactions among contaminants, and compost operating parameters on microbial kinetics have not been fully defined.

The data in Table 2-1 indicate that, of the four explosives present in these experiments, TNT is most rapidly transformed, while HMX is most slowly transformed. Transformation rates for RDX typically lie between these for TNT and RDX. The single estimate of a tetryl degradation rate presently available indicates that its degradation is approximately as rapid as TNT. As previously noted, the possible presence of a lag phase prior to initiation of biotransformation must also be considered in evaluating treatment time.

As with all waste treatment processes, the feasibility and economics of composting will be directly influenced by the length of time required for treatment. Treatment requirements may be specified in terms of final residual concentrations in the product or in terms of required treatment efficiency (i.e., as percentage removed), and may be developed on a site-specific basis. The treatment period is affected by many factors, including soil loading and explosives concentrations. These factors are inter-related in that for a given explosives concentration in soil, the compost explosives concentration will increase with increasing soil loading.

As noted previously, the effect of initial explosives concentration on the rate and extent of reaction is not fully understood. It is well known that the rate of microbial oxidation of substrates is not always an increasing function of substrate concentration. For some organics a concentration may exist above which microbial oxidation may decrease as a result of inhibitory or toxic effects of the substrate. Even when not serving as a substrate, toxic organics may inhibit microbial activity. An upper concentration limit may exist for explosives composting, although its value has not yet been determined.

In terms of the potential toxicity of the explosives in the composting process, the addition of carbon sources and bulking agents has the effect of diluting the bulk explosives concentration to lower levels, possibly lowering the likelihood of toxic effects. However, it should be noted that significantly higher localized concentrations are likely to persist to the extent that the mixture is not truly homogenous. The mixing ratios and resulting compost explosives concentrations at which previous studies have been conducted provide one estimate of the raw sediment explosives concentrations that can be successfully treated. The extent to which higher raw explosives concentrations would necessitate lower ratios of sediment to compost or other changes will directly affect engineering design and operating parameters. Even within the acceptable concentration range, the specific rate constant may vary with initial concentration.

It should also be noted that a variety of factors other than substrate concentration may limit the extent of transformation. Commonly cited examples include the accumulation of inhibitory reaction products, certain microbial population effects, and other changes in environmental conditions. To some extent such limitations are inherent in batch treatment processes, and the heterogeneity of a compost mixture may also play a role. Whether such interactions actually determine the extent of reaction, and whether operational strategies exist that can mitigate such effects, is not yet known.

2.4 HEAT TRANSFER

During the composting process, heat is generated by microbiological activity. Heat is lost from the compost pile by four distinct mechanisms: conduction, convection, radiation, and evaporation [6]. In the absence of forced aeration (such as in conventional windrow composting), conduction is the primary mechanism of heat transfer within the pile. Heat generated within the pile is transported from one compost particle in contact with another. Assuming the exterior pile temperature to be lower than that in the center, a temperature gradient exists to drive the conductive transfer.

Convection occurs as a result of fluid motion. Examples of convective heat transfer in a composting system include losses to a forced aeration stream, to natural convection in the absence of forced aeration, and to a moving air stream on the compost surface (wind).

Radiant losses from the system occur as a result of the higher temperature of the compost pile relative to the surroundings. Additional heat removal also occurs by evaporative losses from the compost mixture.

During composting, aeration rates and/or mixing are used to maintain the targeted temperature range by empirically balancing the heat generated by microbial activity against heat losses caused by conduction, convection, radiation, and evaporation [6]. The balance may be difficult to maintain as the air added to cool the pile through evaporation and convection also supplies the oxygen needed to accelerate microbial activity. In the case of windrow composting, the action of turning the composting material serves to cool the pile by convection as well as supplying needed oxygen by introducing air into the pile.

2.5 PROCESS CONTROL

With an understanding of the effects of reaction conditions on rate, the possibility of controlling or manipulating these parameters in order to optimize performance can be considered. Operating variables that may be under engineering control in a compost system include temperature, aeration, mixing regime, nutrient conditions, and moisture level. In the case of soils composting, the composition and characteristics of the organic amendment mixture may also be manipulated to help control the process.

Several of these parameters are, of course, interrelated. Aeration will directly affect moisture levels by evaporation and will affect temperature both through the direct removal of heat and by evaporative cooling. In fact, for a given waste matrix, aeration may be the major process operation parameter used.

Finstein et al. [8 to 11] argue that the most effective process control for composting operations generally centers upon temperature. In municipal composting systems, this temperature control is generally achieved by drawing or forcing air through the compost with a mechanical blower.

Table 2-1

Kinetic Parameter Estimates for Explosives Composting

Study	Conditions	Soil Ratio (Mass %)	Constituent	k (d^{-1})	Half Life (days)
ARCS [12] Pilot Demonstration SPR	Pilot test, hay/horsefeed mixture (Tank 1)	10.8	TNT RDX HMX Tetryl	0.056 0.035 0.022 NA	12.4 19.8 31.5 NA
	Pilot test, hay/horsefeed mixture (Tank 2)	12.1	TNT RDX HMX	0.071 0.030 0.021	9.8 23.0 33.2
	Pilot test, manure mixture (Tank 5)	11.0	TNT RDX HMX Tetryl	0.097 0.040 0.030 0.082	7.2 17.3 23.0 8.4
WESTON [1]	Field demonstration, hay, manure, horsefeed, fertilizer mixture, mesophilic (Pile 3)	24.0	TNT RDX HMX Tetryl Total Explosives	0.032 0.023 0.016 NS 0.026	21.9 30.1 42.0 NS 26.6
	Field demonstration, hay, manure, horsefeed, fertilizer mixture, mesophilic (Pile 4)	24.0	TNT RDX HMX Tetryl Total Explosives	0.058 0.040 0.030 ND 0.043	11.9 17.3 22.8 ND 16.2

Table 2-1

Kinetic Parameter Estimates for Explosives Composting (Continued)

Study	Conditions	Soil Ratio (Mass %)	Constituent	k (d^{-1})	Half Life (days)
WESTON [5]	Field demonstration, ASP hay, manure, potato mixture, thermophilic (Control D)	52.0	TNT RDX HMX	0.1452 0.0691 0.0241	4.8 10.0 28.8
	Field demonstration, alfalfa, manure, potato peel mixture, thermophilic (aerated windrow)	52.0	TNT RDX HMX	0.1554 0.1207 0.0363	4.5 5.7 19.1
	Field demonstration, alfalfa, manure, potato peel mixture, thermophilic (unaerated windrow)	52.0	TNT RDX HMX	0.1452 0.1554 0.0861	4.8 4.5 8.1

Notes: NA = Not applicable.
ND = Not determined. Contaminant was not present above detection limits in initial compost mixture.
NS = Not sampled.

The need for process control parameters leads to a discussion of composting system configuration. Many new municipal sewage sludge compost facilities are of the aerated static pile configuration in which air is drawn or forced through a pile of composting material by mechanical aeration equipment. Many examples still exist of windrow composting in which large compost piles are periodically turned (by construction equipment or specially designed composting equipment) to reintroduce oxygen and re-establish composting conditions. More recent developments involve mechanical, in-vessel (reactor) composting systems in which, generally, composting mixtures are mechanically agitated. In theory, the intent of such systems is to provide a higher degree of process control as compared to, for example, the aerated static pile system. In order to be of practical value, however, a process control improvement must improve reaction rates sufficiently to compensate for the associated increase in capital and operating costs.

Simpler, alternative methods of improving process control may be postulated, particularly in the case of temperature control. For example, the use of heat trapping enclosures, such as greenhouses, and waste heat from other processes might conceivably supplement microbial processes in maintaining compost temperatures. In cases such as municipal composting systems, where excess metabolic heat is generated, these alternatives would not be useful. However, in the case of contaminated soil composting, self-heating does not occur in the absence of supplemental carbon. These supplemental carbon sources contribute significant operating costs to contaminated soil composting systems. Thus, economic incentives exist to reduce or optimize the amount of supplemental carbon addition.

SECTION 3

CONCEPTUAL PROCESS DEVELOPMENT

3.1 OBJECTIVE

The primary objective of the conceptual process development section is to describe a windrow composting system for the treatment of explosives-contaminated soils. Although composting of soils will be described in this study, the technologies are also applicable to other contaminated materials, including sediments. This process development section will discuss the primary equipment, facilities, materials, personnel, and regulatory requirements that comprise the conceptual treatment system.

This process development is based upon the use of a windrow composting system, with general operating parameters derived from the previous field demonstration projects [4, 5]. This approach will be compared with the aerated static pile approach previously analyzed [3]. Some potential alternatives, modifications, and process sensitivities will be addressed in Section 4.

3.2 DESIGN BASIS AND ASSUMPTIONS

Based on data collected during the field demonstration projects showing composting of explosives-contaminated sediments at LAAP [1] and UMDA [4, 5], and on published literature for composting of municipal and industrial sludges (see Subsection 2.2), a conceptual design basis for windrow composting of explosives-contaminated soils was developed. While this concept is reasonable in light of current windrow composting experience, it should be recognized that a variety of technically acceptable variations may exist.

3.2.1 COMPOST PAD CONFIGURATION

A windrow configuration located on a RCRA-approved pad in an enclosed structure (approximately 300 ft by 75 ft) was established for the design basis. Potentially applicable RCRA regulations are described in Appendix B. The trapezoidal windrows would be 14 ft wide at the base and 240 ft long. Although it would be possible to modify the basic windrow configuration by adding perforated pipe beneath the windrow and mechanically forcing or drawing air through the compost, data from the UMDA study [5] indicate that mechanical aeration does not improve explosives transformation; thus, the additional capital and operating costs associated with the aeration equipment are not justified.

Windrow composting offers the following potential advantages over other systems:

- Simplest facility design.
- Ease of operation.

- Short retention time for treatment of explosives, based on kinetics from previous studies [4,5].

- Low field facility requirements, with the potential for reuse of mechanical equipment at other sites.

3.2.2 COMPOST PILE SEDIMENT FRACTION

Based on data from the UMDA field demonstration [5], the contaminated sediment fraction in the compost mixture is assumed to be 30% by volume for the baseline case. This estimate does not consider the maximum allowable bulk explosives concentration with respect to microbial toxicity and/or process kinetics.

Previous composting studies have been conducted at initial bulk explosives concentrations up to 18,000 mg/kg.

3.2.3 COMPOSTING TREATMENT PERIOD

This conceptual development is based upon an assumed treatment requirement of 99.5% removal of TNT. Based upon data from the UMDA study (presented in Table 2-1), the minimum composting period for contaminated soils to achieve approximately 99.5% removal of TNT for the windrow system would be slightly greater than 20 days. Although the calculated half-life would indicate a faster reaction, the composting period is based upon observed values. Therefore, for this study, a conservative compost cycle time of 30 days was assumed. Data from the UMDA studies were used to determine the composting periods for the aerated static pile (ASP) and mechanical configurations for purposes of process comparison. The aerated static pile (ASP) system with 30% contaminated soil achieved 99.5% TNT removal in 60 days [5]. The mechanically agitated in-vessel (MAIV) system requires a 30-day treatment time [4]. Table 3-1 summarizes the projected treatment periods for the three composting configurations considered. Although the kinetic parameters used in this study were calculated solely from TNT data, reduction of RDX levels may also be important. It should be noted that the windrow system achieved the targeted 99.5% removal of RDX while the aerated static pile system did not achieve this reduction. Additionally, the windrow system demonstrated significantly greater HMX reduction than found in ASP or MAIV systems [4,5].

3.2.4 REGULATORY REQUIREMENTS

For purposes of this evaluation, it is assumed that RCRA regulations may be applicable to the composting facility. As such, minimum technology standards will be used for the design. If RCRA requirements are not imposed, facility costs would be reduced. These potential savings will be discussed in Subsection 4.2.1.

There are several situations in which RCRA standards may not strictly apply. For example, CERCLA sites may not require all RCRA criteria, although the RCRA requirements are generally ARARs under CERCLA. As currently understood, it is

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Table 3-1

Project Treatment Periods for Composting

Compost Configuration	Treatment Period* (days)
Windrow	30
Aerated Static Pile	60
Mechanically Agitated In-Vessel	30

*Treatment period based on achieving 99.5% TNT removal.

possible that composting would meet the definition of a waste pile under RCRA, as described in 40 CFR 264 Subpart L. These requirements were summarized in Appendix B. It should also be recognized that the exact requirements for a given site may be determined by the EPA Regional Administrator. However, for the purposes of this report, a double-lined asphalt pad with a leak detection system is assumed to be adequate. It may be possible to eliminate the liner and leak detection system as they are not required for processing but are included as a conservative assumption to fulfill regulatory requirements. Past projects have been conducted on an unlined asphalt pad [5]. Runon and precipitation to the compost will be prevented by covering the asphalt pad with a temporary structure.

Finally, it must be noted that regulations concerning facility requirements may change in the future.

3.2.5 FACILITY SIZE

Composting facilities considered in this evaluation were sized to process 20,000 tons of soil in 5 years using a compost mixture of 30 volume percent contaminated soil. Both the volume of material to be treated and the allowable remedial period may vary widely from site to site. Design and operating requirements for the windrow system are presented in the following sections. Throughout these sections, quantities of soil will be expressed in units of either tons or cubic yards, as appropriate.

3.2.6 WATER (DRAINAGE) MANAGEMENT

It is assumed that composting is essentially a water-consumptive process so that, if rainfall and runon (any rainwater, leachate, or other liquid that drains over and onto any part of a facility) are controlled, no net generation of drainage would occur from the compost pile. Rather, the addition of small quantities of makeup water would be required. This assumption is well supported by field demonstration experience. A temporary (field erected) structure will be used to control precipitation runon (as well as to help control environmental conditions for effective composting). A berm will be provided to control any accidental spills of makeup water. No additional water management systems will be needed except exterior site grading to provide surface drainage of precipitation on uncontaminated surfaces.

3.2.7 AERATION REQUIREMENTS

Aeration (and mixing) would be accomplished through turning the windrow with a commercially available compost turner. The amount of aeration would be determined by turning frequency. Previous work at UMDA [5] has shown that the percent oxygen maintained in this configuration is relatively low (generally 1 to 5%). It was also shown, however, that the targeted TNT removal was accomplished by the process. Additionally, RDX and HMX were reduced by 99.8% and 96.8%, respectively. Available data also indicate that this mode of operation is acceptable in terms of toxicity and mobility reduction as well [17].

3.2.8 MIXING REQUIREMENTS

In addition to providing aeration for the windrow, mixing with the windrow turner also homogenizes the compost. Initially, the windrow turner would be passed through the compost several times to thoroughly mix the initial material. The windrow turner would then be used to mix the compost daily throughout the composting period. The turning frequency may be altered based on temperature requirements.

3.3 PROCESS DESCRIPTION AND MATERIALS BALANCE

A process flow diagram (Figure 3-1) and mass balance have been developed based on the previously stated design basis.

In terms of actual materials flow through the system, system operations may be divided into three categories: windrow construction, windrow operation, and finished compost disposition. Although for a given windrow these phases are sequential, activity will be ongoing in different phases for different windrows in the facility at any one time.

Several aspects of the system mass balance are presently indeterminate. In particular, the fate of organic materials in the exit streams is unknown. Basic assumptions were needed to perform the mass balance:

- Soil fraction - The biologically inert soil mass is expected to be conserved and to exit the system completely in the final compost (Stream 5).

- Organic (amendment) mixture - The amendment mixture serves as a substrate for microbial growth and heat generation. Therefore, a portion of this material is metabolized during composting. Of the portion metabolized, a fraction is mineralized to end products, including carbon dioxide and water, expressed in the exit gases (Stream 4) and final compost mixture (Stream 5). The degradable portion not mineralized would be expressed as an increase in microbial mass in the final compost mixture. Finally, the amendment material not degraded, as well as the minor inorganic fraction, will be retained in the final compost mixture.

- Moisture - Moisture would leave the mixture primarily through evaporation in the exit gas (Stream 4), assuming that the moisture addition rate is controlled to prevent leachate generation.

The net effect of these factors on the final compost mass for disposal has not been fully determined. There is some volume loss during composting as a result of loss of mass from microbial metabolism as well as from settling and compaction.

3.3.1 PROCESS DESCRIPTION

The windrow composting process is made up of five basic materials handling steps:

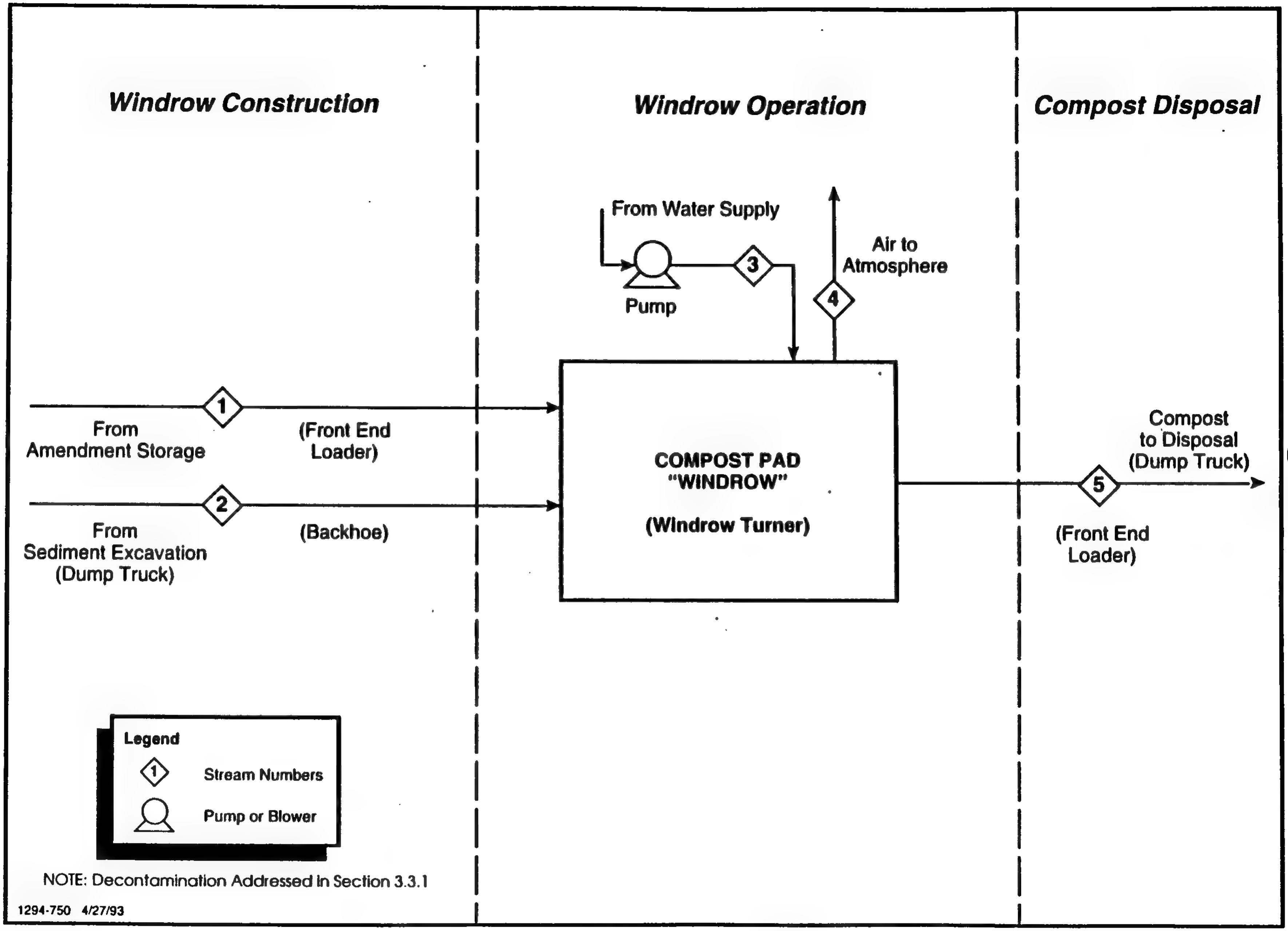

FIGURE 3-1 PROCESS FLOW DIAGRAM FOR WINDROW COMPOSTING SYSTEM

1. Soil excavation/staging.
2. Amendment materials preparation.
3. Windrow construction.
4. Windrow operation.
5. Windrow removal and disposition of treated compost.

Two trapezoidal windrows (240 ft long by 14 ft wide at the base) will be processed at a time. The windrows will be constructed on an asphalt pad (300 ft by 75 ft). Twelve processing cycles per year will occur.

The following subsections provide a description of the major equipment and various materials handling steps that are included in the conceptual compost system and based upon the process flow and materials balance information provided in Figure 3-1 and Table 3-2. In the description that follows, equipment sizes and capacities are provided consistent with these requirements. References to specific equipment by manufacturer or model number are used for illustrative purposes and do not exclude the use of other similar equipment.

3.3.1.1 Soil Excavation/Staging

Contaminated soil would be excavated from the source area and loaded into a 12 yd^3 lined dump truck. When the dump truck is filled with soil, it would be moved to the composting area. The dump truck would be parked or staged adjacent to the composting building and used as a storage and/or feed container for the soil prior to their incorporation into the windrows. After the dump truck is emptied, any free standing water remaining would be removed to the sump. Upon completion of its use in the composting area, the dump truck would pass through a wheel wash to prevent contamination.

For the baseline facility presented in previous sections, the estimated soil volume to be excavated is 145 yd^3 per windrow (3,500 yd^3 per year). Twenty-four windrows (12 cycles of two windrows each) per year will be processed.

3.3.1.2 Amendment Materials Preparation

For purposes of this evaluation, the amendment materials used during the composting process would include alfalfa, sawdust, manure mixture, and potato waste. The mixture was developed during the UMDA field study [5]. Other mixtures may be required at other sites as a result of variations in local availability. The amendment delivery and staging area would be located outside of the composting area and, thus, is isolated from contact with the contaminated soils in order to minimize costs and materials associated with decontaminating trucks and equipment. The amendment materials would be staged on an asphalt pad and covered with plastic sheeting when windrows are not being constructed. A front-end loader with a 2 yd^3 bucket would be used to move the amendments into the composting area. The uncontaminated front-end loader would empty the amendments onto the edge of the pad without driving onto the pad. A front-end loader inside the contaminated area would move the amendments from the pad

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Table 3-2

Mass Balance for Windrow Materials Stream[a]

Stream Component	Units	1	2	3	4	5
Mass Flow[b]	pounds[c]	321,100	333,500	4,615	u[e]	u[e]
Volume Flow[b]	cubic yards[d]	338	145	3	u[e]	u[e]

[a]Refers to Figure 3-1.
[b]Refers to one windrow.
[c]Pounds per day.
[d]Cubic yards per day.
[e]Undetermined.

Note: Assumed densities:

- Soil - 2,300 lb/yd^3
- Amendments - 950 lb/yd^3
- Compost - 1,355 lb/yd^3

edge to the windrow. The front-end loader located outside of the pad would not require decontamination. The front-end loader on the pad would be decontaminated only if leaving the pad. For the concept design, 338 yd^3 of amendments would be required for each windrow (8,120 yd^3 per year). The proposed amendment composition is presented in Table 3-3.

3.3.1.3 Windrow Formation and Mixing

Formation of the windrow would be accomplished with a front-end loader. Windrow formation and mixing would typically be done as follows:

- Stack bales of alfalfa in line along the intended axis of the windrow.
- Cover alfalfa with sawdust.
- Mix the windrow once by passing over it with the compost turner (Scarab Model 14 or equivalent).
- Add manure mixture and potato waste.
- Mix with compost turner.
- Add contaminated soil.
- Mix with compost turner twice more to homogenize mixture.

If necessary, a front-end loader may be used to reform the edges of the windrow after mixing.

The Scarab Model 14 was chosen for this study because vendor literature was available describing windrow dimensions and projected operating costs [15]. This detailed information was not readily available for other similar machines, such as Resource Recovery Systems' KW-614, which was used in the UMDA field study [5]. A compilation of available windrow turners is presented in Appendix A. A sketch of a typical windrow turner and windrow cross-section are presented in Figure 3-2.

3.3.1.4 Windrow Turning

To provide thorough compost homogenization and ensure contact between microorganisms and contaminants, the compost would be turned daily. During turning, oxygen would be introduced into the windrow and some heat removed from the compost. This is accomplished using the compost turner described in Subsection 3.3.1.3. One pass through each windrow would be needed. As before, the windrow edges may be reformed using a front-end loader. As composting progresses and microbial activity declines, the turning frequency may be decreased. A relatively small cost savings would result if less frequent turnings were required. The majority of the cost associated with turning the windrows is in the acquisition of the windrow turning

Table 3-3

Amendment Composition

Material	Volume (%)
Sawdust	25
Alfalfa	25
Chicken manure	5
Cow manure	30
Potato waste	15
Total	100.0

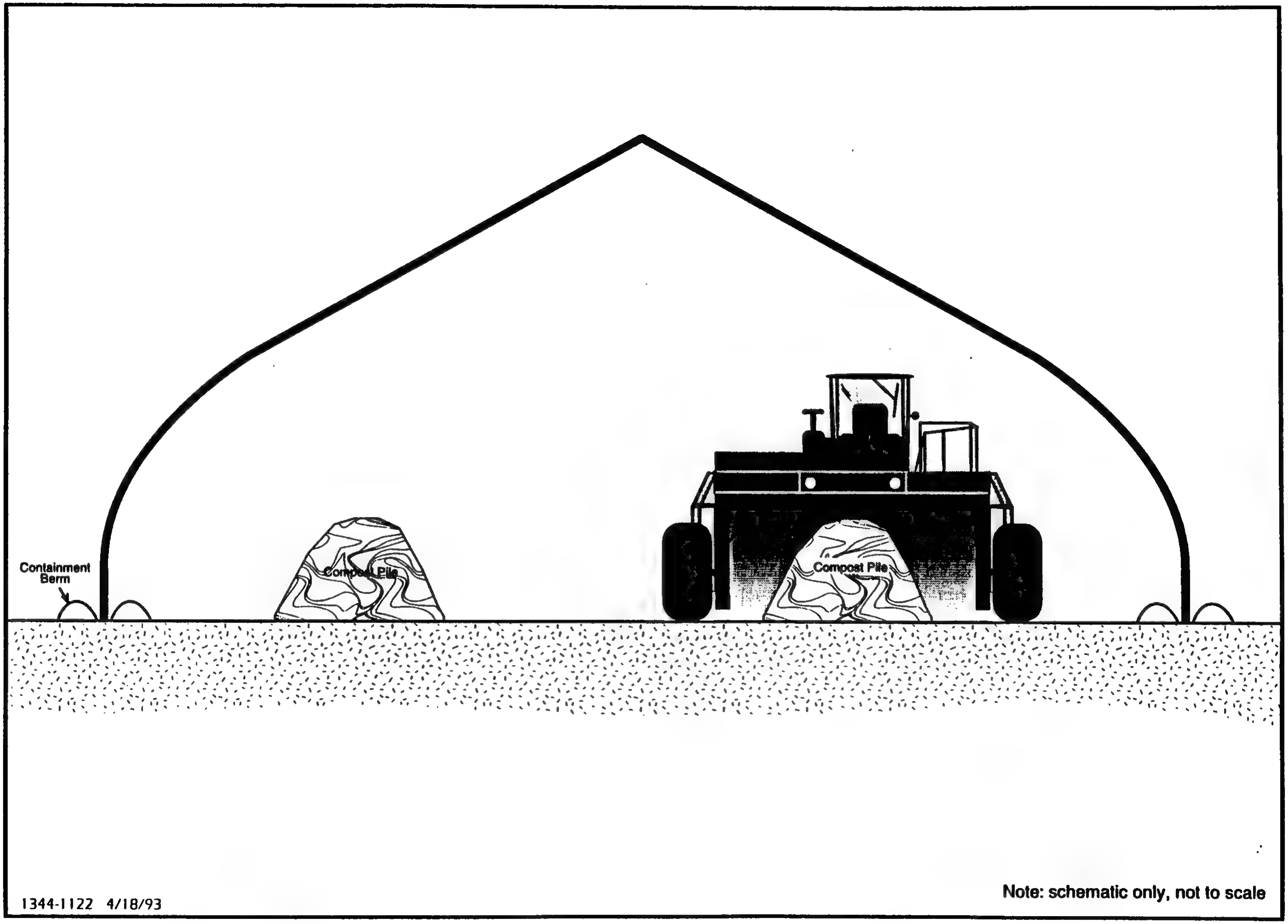

FIGURE 3-2 CROSS-SECTION OF TYPICAL WINDROW TURNER AND COMPOST PILE

machine. Because one machine would be needed regardless of the turning frequency, reduction of the frequency would only save the labor and fuel costs associated with turning.

3.3.1.5 Windrow Monitoring

Windrows would be monitored for temperature, percent oxygen, percent moisture, pH, and explosives concentration. Monitoring frequencies are presented in Table 3-4.

Temperature would be monitored using thermocouples in conjunction with a 6-ft temperature probe (commonly known as a landfill probe) and a hand-held digital controller. Temperature would be monitored at six points along the length of the pile before turning. The number of monitoring locations may be increased if a large variability is seen between the sampling points.

In previous studies [5], interstitial oxygen was seen to drop rapidly to an equilibrium value soon after turning. The oxygen level at this equilibrium would be monitored daily prior to turning using a hand-held oxygen meter. The meter would be attached to a landfill probe inserted into the windrow. Air would be manually drawn through the probe with a hand pump until a steady oxygen value is obtained.

Percent moisture would be monitored twice weekly. In each case, four samples per windrow are needed (with three replicates each). Water would be added as needed to maintain the required compost moisture content. Three pH samples per windrow would be taken at the same time as the windrow samples.

Explosives concentrations would be analyzed at a laboratory on days 0, 10, 20, and 30. In each case, one composite sample would be made from four discrete points and sent off-site for analysis.

3.3.1.6 Windrow Removal and Disposition

After the composting period is complete, a front-end loader would be used to remove the finished compost from the windrows and remove it to a staging area outside of the structure. From the staging area, a covered dump truck would transport the finished compost to its final disposition. It is assumed the compost would have been treated to meet cleanup criteria and so could be replaced in the area from which the contaminated soil was excavated and covered with soil. Because of the increase in volume that occurs when the amendments are added for composting, there would be more finished compost than contaminated soil by volume. Thus, a mound may be formed at the disposal site. This mound would be covered, graded, and seeded at the close of the project. It should be noted that during the composting process, a volume reduction occurs so that the finished compost volume is less than that of the starting materials, although still greater than the volume of original soil. At the final disposal site, the compost will be graded to a 3% slope. The area would be covered with 18 inches of common borrow and 6 inches of vegetative cover.

Table 3-4

Windrow Monitoring Frequency

Parameter	Frequency	Number of Locations
Temperature	Daily	6
Percent Oxygen	Daily	6
Percent Moisture	Two times/week	4
pH	Two times/week	3
Explosives concentration	Day 0, 10, 20, and 30	Composite of four samples

3.3.2 PROCESS FLOW DIAGRAM/MATERIAL BALANCE

Figure 3-1 and Table 3-2 present the process flow diagram and material balance for a windrow composting system operating under previously discussed conditions. As windrow construction occurs only twice every 30 days, rates are presented in terms of material for one windrow. Water addition flows are given as daily rates.

Contaminated materials would be excavated using a backhoe and transported from the excavation area to the composting area in a dump truck. To construct one windrow, 145 yd^3 of sediment would be required. Amendments (338 yd^3) would be transported from their staging area by a front-end loader to the composting area. After the windrow is formed, a windrow turner would be used to thoroughly mix the compost. During the composting period, approximately 560 gallons of water would be added to each windrow. The windrow turner would be used to mix the compost daily.

After a composting period of 30 days, the compost would be removed from the windrow with a front-end loader and transported to a staging area. The compost would then be moved in a dump truck for final disposition.

3.4 FACILITY DESCRIPTION

3.4.1 GENERAL

This subsection describes a conceptualized compost facility used to treat explosives contaminated sediments. This facility is based on the background review and regulatory issues discussed in Section 2 and the conceptual process development discussed in previous portions of Section 3.

These facilities have been developed on the conservative assumption that RCRA minimum technology standards may be applicable to the soils. If this approach is necessary, RCRA waste pile design standards would apply on positive control of leachate generation (including a liner and leak detection system) and runoff would be required. This design is likely the most costly approach to facility design and operation. It will be shown in Section 4 that elimination or reduction of these RCRA hazardous facility waste design standards would significantly decrease the facility cost.

A facility description and major equipment list are presented in the remainder of Section 3. Estimated capital and operations and maintenance (O&M) costs are presented in Section 4.

3.4.2 SITE LAYOUT

The composting facility centers on the RCRA-approved asphalt pad where the windrows would be constructed (300 ft by 75 ft). If required by RCRA, the entire paved area would be built over a liner with a leak detection system and surrounded by a berm to prevent runon to the site. Potential RCRA requirements are described in Appendix B. A temporary structure covers the area so that precipitation would not reach the

compost and runoff would not be generated. A conceptual site layout is presented in Figure 3-3.

Contaminated soils would enter the facility in a dump truck. The dump truck would serve as a staging area adjacent to the composting facility until the soil is placed in the windrow. If the truck would be required to enter the contaminated zone at any time, wheels of the dump truck would be decontaminated in the wheel wash prior to leaving the contaminated area. Amendments would be stored on an asphalt pad adjacent to the composting structure. They would be transported to the windrow during construction with a front-end loader. The wheels of the front end loader would be decontaminated in the wheel wash prior to leaving the building.

Finished compost would be staged on an asphalt pad adjacent to the composting structure prior to being moved in the dump truck to final disposal.

3.4.2.1 Compost Area

The composting area would be paved with asphalt. The pad would be designed to be structurally sound beneath the weight of operating equipment.

The paved area would be surrounded by a containment berm. A sump would be located at one end of the pad to contain any water generated inside the building. The entire area encompassed by the berm would have a geomembrane liner with a leak detection system under the asphalt to satisfy RCRA requirements as described in Appendix B. The area would also be covered with a temporary structure, such as a clamshell structure.

3.4.2.2 Site Support Facilities

The site support facilities have been minimized to reduce costs. The support facilities consist of an office trailer for operating personnel and a portable toilet. The office trailer would contain equipment for on-site process monitoring and maintenance, showers, emergency eyewash equipment, first aid equipment, and potable water.

3.4.3 SITE OPERATION/MANAGEMENT

The facility layout has been designed for optimal control of materials handling and composting operation. The following subsections describe the windrow operating cycle and water management plan.

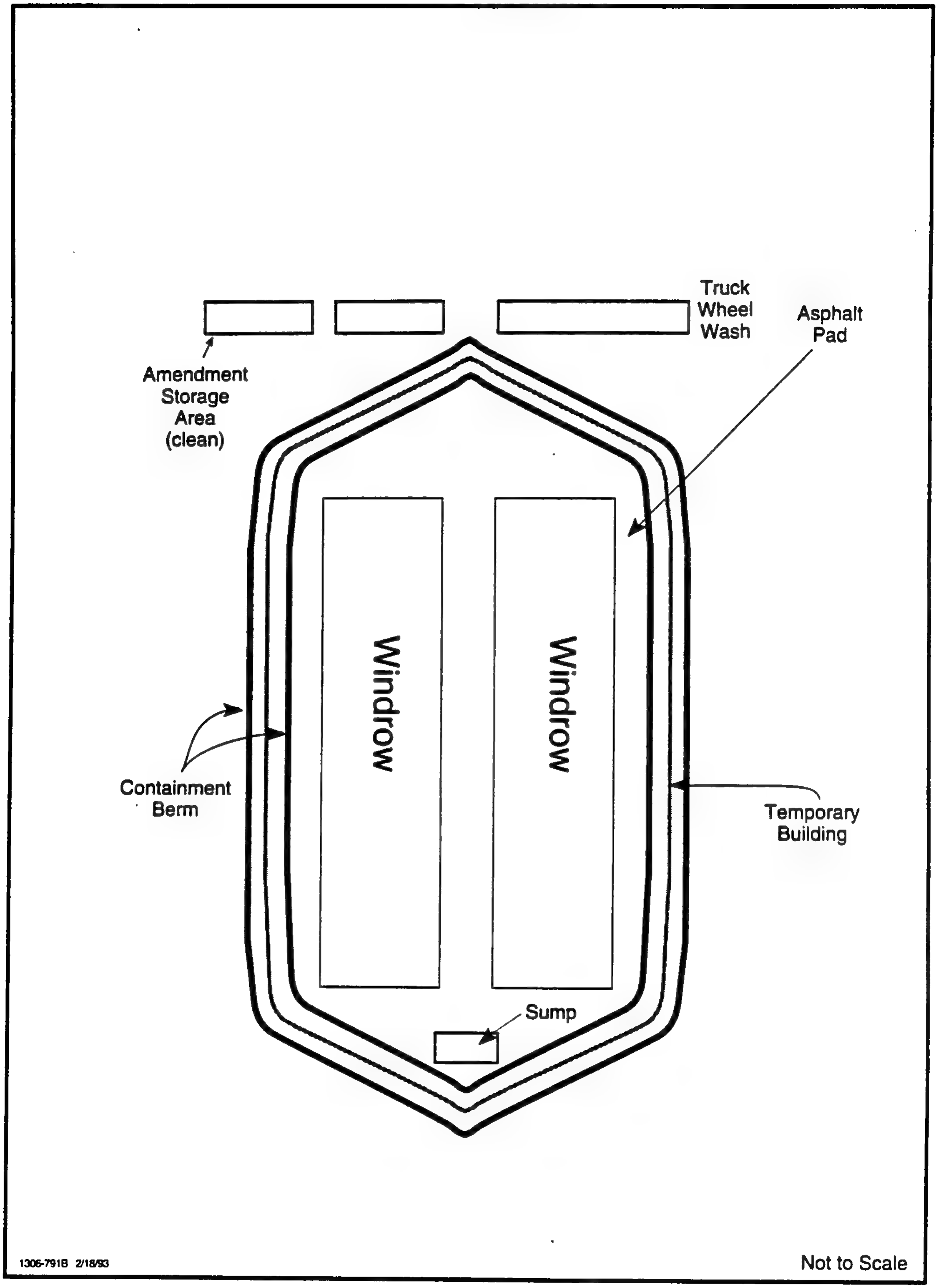

FIGURE 3-3 SITE LAYOUT FOR WINDROW FACILITY

3.4.3.1 Windrow Operating Cycle

At the beginning of the operating cycle, amendments and soil would be formed into a windrow and mixed with a windrow turner. Daily temperature readings would be taken using thermocouples in conjunction with landfill probes and oxygen readings would be taken using an oxygen meter. Percent moisture and pH would be monitored twice weekly. The windrow turner would be used daily to mix the compost.

At the end of the composting period, the windrow would be disassembled and the finished compost taken to a final disposal area. Approximately 1 day will be required to assemble and 1 day to disassemble each windrow.

3.4.3.2 Water Management

Water runon and runoff from the windrows will be prevented by installation of a containment berm and a temporary structure to prevent precipitation and runon onto the compost. The composting process itself is water-consumptive and thus will not generate leachate.

3.5 FACILITY DESIGN AND OPERATING REQUIREMENTS

3.5.1 EQUIPMENT LIST

The major equipment list for the facility is presented in Table 3-5. This list includes all major operating equipment required for soil excavation, materials handling, and windrow construction and turning.

3.5.2 CONSTRUCTION REQUIREMENTS

It is assumed that the windrow-composting system will utilize the RCRA facility design requirements including a liner system. Facility features in compliance with RCRA include:

- Site preparation
    - Clearing and grubbing.
    - Excavation for area system.
    - Subgrade preparation.
    - Final site grading.
    - Seeding and mulch.
- Asphalt work
    - Site paving (6 inches crushed gravel, 6 inches asphalt).
    - Containment berm.
- Building

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Table 3-5

Major Equipment List for Windrow System

Equipment	Quantity Required	Capacity/ Dimensions	Type
Backhoe	1	1 yd^3	Caterpillar 225 or equivalent
Dump Truck	1	12 yd^3	--
Front-End Loader	2	2 yd^3	Caterpillar 926 wheel loader or equivalent
Water Pump	1	10 gpm	Centrifugal; explosion-proof
Windrow Turner	1	14 ft base	Scarab Model 14 or equivalent

- Temporary structure to prevent precipitation from reaching the windrows and for site security.

- Geosynthetic lining system

    - Including a 40-mil geomembrane liner, a 12-inch sand layer, and a leak detection system.

3.5.3 OPERATING REQUIREMENTS

3.5.3.1 Control Parameters

The primary control parameters for windrow composting would be:

- Windrow-turning frequency.
- Water addition.

Windrow-turning frequency determines the rate of oxygen addition as well as lowering of the windrow temperature. Water addition would be used to maintain an optimal moisture content and also slightly lowers the compost temperature.

3.5.3.2 Utilities Requirements

The primary utilities required on-site for operation would be:

- Water for addition to compost and for equipment decontamination.
- Diesel fuel for heavy equipment.
- Electric power for lighting and equipment.

3.5.3.3 Personnel

The size of the baseline facility would require a small crew of two operators and one technician. Because of the limited number of employees, they must be versatile individuals, trained in heavy equipment operation, compost monitoring, facility maintenance, reporting, and other tasks required during windrow operation. Explosives analysis would be conducted at an off-site laboratory.

3.5.4 SITE CLOSURE

Finished compost would be returned to the area where the contaminated soil was excavated. Because the volume of compost returned would be greater than the volume of soil excavated, a mound would be formed. At the end of the treatment period, the disposal site would be capped and a vegetative cover applied. Closure procedures could be altered by regulatory requirements.

SECTION 4

ECONOMIC ANALYSIS

The applicability of windrow composting as a viable alternative for treatment of explosives-contaminated soils will be partly determined by its relative cost. Cost information is available for conventional (MSW and sludge) composting systems. Additionally, cost information is available for aerated static pile or mechanically agitated in vessel explosives composting based on the experiences gained in the previous field demonstrations [3].

In this section, potential costs associated with windrow composting of explosives-contaminated soil are developed. These estimated costs are based on the processing equipment and parameters developed in Section 3 and experience gained in the UMDA field demonstration [5]. This analysis is intended to evaluate and illustrate the potential economic feasibility of windrow composting as a treatment technology and to identify areas where process optimization may be economically favorable.

4.1 ECONOMIC ANALYSIS - BASE CASE SYSTEM

4.1.1 CAPITAL COSTS ESTIMATE

4.1.1.1 Methodology and Assumptions

Capital costs for the windrow system presented in Section 3 were developed using conventional construction cost estimating procedures. Facility dimensions, material requirements and quantities, and methods of construction were based on the site layout and process development presented in Section 3. Unit and total prices for facility construction were based on a standard construction cost reference [13]. Unit prices for equipment were obtained either from standard references for conventional equipment or from vendor quotes for agricultural or specialized compost equipment. Cost estimates are considered to be accurate in the range of +30% to -15%. Table 4-1 presents major items included in the capital cost estimate.

4.1.1.2 Geographic/Site-Specific Assumptions

The conceptual technical approach developed in this report is applicable to a variety of sites and situations. However, the specific geographic, meteorological, and environmental conditions and location-specific factors at any given site may affect system costs. For purposes of this analysis, the following generalizations were made:

- Site costs were developed based on level topography. Substantial deviations in land elevation would increase the cost for site preparation.

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Table 4-1

Major Items Included in Potential Capital Costs for Windrow Composting System

Equipment

- 1-yd^3 backhoe.
- 12-yd^3 dump truck.
- 2-yd^3 front-end loader.
- Windrow turner.
- Water pump (for sump).
- Monitoring equipment.

Sitework

- Clearing and grubbing.
- Bulk excavation.
- Grading
- Paving.
- Seeding and mulching.
- Cap for finished compost backfill.

Buildings and Structures

- Temporary structure (one structure - 300 ft x 75 ft)

- Liner system.

Mechanical/Piping

- Site drainage and storm runoff control.

Electrical

- Equipment power distribution.
- Site lighting.

- The composting site was assumed to be located in close proximity to the contaminated area to minimize hauling requirements. If this close proximity is not possible, the costs would increase for transport of contaminated soil and finished compost.

- Necessary site utilities (e.g., electric and water) are assumed to be provided to the site by the facility. Cost for providing utilities to the site are not included.

- The potential cost for permitting or regulatory approval of the composting treatment facility are not included in these estimates. Although compost disposition and facility decontamination costs are included, no costs have been included for facility demolition or removal. These costs may be variable.

4.1.1.3 Contingency

A contingency factor (generally as a percentage of total capital) is conventionally added to various types of cost estimates to allow for unknown and unforeseeable factors or changes which may develop. Costs in this report are presented with a 15% contingency factor.

4.1.1.4 Project Financing

It has been assumed that construction funds would be obtained through government appropriations on a fiscal year basis. Therefore, no costs associated with project financing are included.

4.1.1.5 Results

Potential capital costs associated with a 20,000 ton windrow-composting facility are presented in Table 4-2. Within the previously discussed constraints, the total capital costs are estimated at $2,118,000.

4.1.2 O&M COST ESTIMATE

4.1.2.1 Methodology and Assumption

Estimates of potential O&M costs were developed based upon the conceptual layouts presented in Section 3. The following description presents the basic procedure used in developing this estimate.

The potential materials requirements and materials handling requirements were estimated from the process description in Section 3. Productivity and fuel consumption rates were obtained from equipment vendor sources [14,15,16], published data [13], or previous experience [5], and used to estimate total operational hours and fuel for such activities as windrow construction, windrow turning, and windrow dismantling.

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Table 4-2

Estimated Capital Costs for Windrow Composting System

	Cost ($)
Equipment	567,000
Site Work	280,000
Buildings/Structures	322,000
Mechanical/Piping	26,000
Electrical	129,000
First Subtotal Capital	**1,324,000**
Project Construction Facilities/Mobilization/Demobilization @ 8%	111,000
Construction Equipment, Consumable Items @ 5%	69,000
Fees @ 1.5%	20,000
Second Subtotal Capital	**1,524,000**
General and Administrative Overhead Costs @ 9.5%	150,000
Contractor Markup and Profit @ 10%	168,000
Contingency @ 15%	276,000
Total	**2,118,000**

Manpower requirements for these activities, including equipment operators and laborers, were estimated based upon previous operating experience. From these estimates, annual operating costs associated with compost production were estimated using the unit costs presented in Table 4-3.

The total cost of amendment materials was estimated based upon quantities presented in Section 3. Unit prices are based on prior experience at UMDA [5]. These costs are based on the purchase price of the amendments and the delivery fees.

It was assumed that finished compost would be backfilled on-site in the original excavation. If the more costly option of off-site disposal (e.g., landfilling) after treatment is required, the economic viability of this process would be impaired, particularly because the total material requiring off-site transportation and disposal would be greater than the original volume of contaminated soil. Therefore, it is assumed that the finished compost would be used on-site. The costs of excavation and backfilling are included in the annual operating costs. It is assumed that soil would be excavated and finished compost returned to the excavation area as needed.

Maintenance was estimated at 3% of the total capital cost. This represents the scheduled preventive maintenance on all mechanical equipment (e.g., oil change and fluids change) and other routine activities (e.g., equipment servicing and calibration) required to maintain full scale operation of the facility equipment.

A 5-year project length was assumed in these analyses. The useful life of the facility would likely be significantly longer than this period, so equipment replacement costs are not considered. If salvage values resulting from equipment reuse at other sites are considered, cost savings will result. These savings are described in Subsection 4.1.3.

O&M costs were converted to present worth assuming an 8% annual interest and 5 year project life. Present worth calculations assumed equal annual O&M costs each year for 5 years and are presented in 1993 dollars. Capital costs were assumed to be in terms of present value. As with the capital costs, a 15% contingency was applied to the annual O&M costs.

4.1.2.2 <u>Results</u>

The windrow composting system estimated operating and maintenance (O&M) costs are presented in Table 4-4. The total annual O&M cost (including 15% contingency) is estimated at $527,000. This corresponds to a 5-year present worth of $2,104,000 (including 15% contingency).

4.1.3 TOTAL PROJECT COST

The total 5-year project cost of the windrow composting system as presented herein is estimated to be $4,222,000. For treatment of 20,000 tons of soil (5,000 tons/year) in this period, this translates to a cost of $211 per ton. This estimate includes costs

Table 4-3

Operation and Maintenance Unit Costs

Area	Unit Costs ($)
Labor[a] Operators Technician	 20/hour 16/hour
Electric	0.07/Kwhr
Diesel Fuel	1.10/gallon
Amendments[b]	50/ton
Analytics (off-site)[c]	220/sample

[a]Does not include overhead costs.
[b]Based on a previous experience for delivered amendments [5].
[c]Based on previous experience.

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Table 4-4

Estimated Annual O&M Costs for Windrow Composting System

Area	Annual Cost ($)
Power	1,000
Amendments	195,000
Wood Chips	0
Diesel Fuel	19,000
Labor	116,000
Analytics (off-site)	21,000
Maintenance	64,000
Subtotal Annual O&M	416,000
Contractor Markup and Profit @ 10%	42,000
Contingency @ 15%	69,000
Total Annual O&M	**527,000**
Total 5-Year O&M (P/W)	**2,104,000**

associated with excavation and final disposition in addition to treatment costs. Approximately 50% of these costs are attributable to capital expenditures and 50% to total present-worth O&M costs.

Much of the major equipment would still be usable at the close of the 5-year project. As such, a salvage value may be calculated and its present worth subtracted from the project capital costs in order to more accurately determine the costs of the project. Based on vendor information [14,15], a 10-year useful life was assumed for the windrow turner and temporary structure. Based on common estimating practices, a 10-year useful life was also assumed for the backhoe, dump truck, and front-end loader. Using the straight-line depreciation method over the 10-year useful life of the equipment, a total salvage value was determined. At the end of the 5-year period, this equipment could be used at another composting site or sold as construction equipment.

After salvage values were included in the project costs, the total 5-year project cost was calculated as $3,977,000. This corresponds to $199 per ton (including salvage values). Project costs with and without salvage values are presented in Table 4-5.

4.2 SENSITIVITY CONSIDERATIONS

The capital and O&M estimated costs developed in this study are based on particular equipment and operating parameters. By varying some of the equipment and parameters, system operation and economics may be changed.

4.2.1 POTENTIAL CAPITAL AND OPERATING COST CHANGES

The conceptual system presented in Section 3 is based on conservative assumptions with respect to system performance goals and regulatory requirements. Depending on the specific site for project implementation, some site-specific physical or climatological conditions may alter capital items to be considered on a case-by-case basis. Items to be considered include:

- Elimination of the RCRA liner under the composting area would represent a significant cost savings. This modification must take regulatory requirements into account. Previous pilot-scale work at UMDA [5] was performed on an unlined asphalt pad. Elimination of the liner and leak detection system assumed in the baseline case translates to a cost savings of approximately $5 per ton of soil. This cost does not account for salvage values.

- One front-end loader may be eliminated if the composting area is reconfigured to allow amendment staging in the contaminated area. This modification translates to a savings of approximately $5 per ton of soil treated.

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Table 4-5

Total Estimated 5-Year Project Cost for Windrow Composting System

	Cost ($)
Without Salvage Values	
Total Capital	2,118,000
Total 5-Year O&M (P/W)	2,104,000
Total 5-Year Project cost (P/W)	4,222,000
Soil Treated in 5 Years (Tons)	20,000
Cost Per Ton of Soil	211
Including Salvage Values	
Total Capital (including Salvage)	1,873,000
Total 5-Year O&M (P/W)	2,104,000
Total 5-Year Project Cost (P/W)	3,977,000
Soil Treated in 5 Years (Tons)	20,000
Cost Per Ton of Soil	199

- In areas where appropriate climatic conditions exist (dry climates without harsh winters), the temporary structure may possibly be eliminated. This modification would result in a cost savings of approximately $10 to $15 per ton of soil. The need to use the temporary structure for dust control must be evaluated.

- If the soil fraction in the compost could be increased from 30 volume percent to 40 volume percent, a cost savings of approximately $5 to $6 per ton of soil is possible. This is based on the assumption that process kinetics would be equivalent at the two soil loadings. This assumption would need to be verified experimentally.

- Reduction of the compost treatment time from 30 days to 20 days would result in a cost savings of approximately $5 per ton of soil. Explosives reduction at the 20-day treatment time would need to be verified experimentally.

- Reduction of the turning frequency from daily to three times per week would result in a savings of approximately $1 per ton of soil.

The potential savings are all relatively small in comparison to the overall project cost.

4.2.2 PROJECT DURATION

The cost per ton of soil processed is dependent on the duration of the remediation period. An analysis was conducted to determine if cost savings could be realized by varying the total project duration from the 5-year baseline case. Capital and annual O&M costs were calculated for treatment periods of 1, 3, 5, 8, and 10 years, corresponding to 20,000, 6,700, 4,000, 2,500, and 2,000 tons of soil/year, respectively. The assumptions and methods used in the 5-year baseline case were extended to all of the cases.

Table 4-6 presents the potential capital cost for the five treatment periods considered. Equipment costs increase as the project duration is shortened. For periods less than 5 years, an additional dump truck (for a total of two) is required. For periods less than 3 years, an additional front-end loader (for a total of 3) is needed. Site-work costs also increase with decreasing treatment period as larger pads and temporary buildings are required. In longer duration projects, equipment may not be fully utilized because of the small volume of compost treated at any one time. Equipment salvage values are not considered.

Table 4-7 presents annual O&M costs for the five treatment periods. Some O&M costs (labor, analytics) appear to reach a relatively constant value at around a 5-year treatment period. At this system size, the minimal crew and sampling frequency for safe, efficient operation is reached. Although the laborers may not be fully utilized at all times, there are times, such as during windrow formation, that three workers are

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Table 4-6

Estimated Capital Costs for Windrow Composting of Varying Project Durations

	Project Duration (years)				
	1	3	5	8	10
Soil Treated Per Year (Ton)	20,000	6,700	4,000	2,500	2,000
Equipment ($)	723,000	634,000	567,000	565,000	564,000
Sitework ($)	846,000	357,000	280,000	171,000	136,000
Structures ($)	1,498,000	349,000	322,000	320,000	281,000
Mechanical/Piping ($)	122,000	53,000	26,000	52,500	16,000
Electrical ($)	209,000	143,000	129,000	123,000	120,000
First Subtotal Capital ($)	3,398,000	1,536,000	1,324,000	1,231,000	1,117,000
Construction Facilities/Mobilization/ Demobilization @ 8% ($)	272,000	123,000	111,000	98,000	89,000
Consumable Items @ 5% ($)	170,000	77,000	69,000	62,000	56,000
Fees @ 1.5% ($)	51,000	23,000	20,000	18,000	17,000
Overhead @ 9.5% ($)	323,000	146,000	150,000	117,000	106,000
Contractor Markup @ 10% ($)	421,000	190,000	168,000	153,000	139,000
Contingency @ 15% ($)	695,000	314,000	276,000	252,000	229,000
Total Capital ($)	5,330,000	2,409,000	2,118,000	1,931,000	1,753,000

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Table 4-7

Estimated O&M Costs for Windrow Composting of Varying Project Durations

	Project Duration (years)				
	1	3	5	8	10
Soil Treated Per Year (Tons)	20,000	6,700	4,000	2,000	1,000
Power ($/year)	4,000	2,000	1,000	1,000	1,000
Amendments ($/year)	980,000	327,000	195,000	122,000	98,000
Fuel ($/year)	88,000	30,000	19,000	11,000	9,000
Labor ($/year)	229,000	154,000	116,000	116,000	116,000
Analytics ($/year)	106,000	42,000	21,000	21,000	21,000
Maintenance @ 3% of Capital ($/year)	160,000	72,000	64,000	58,000	52,000
Subtotal Annual O&M ($/year)	1,567,000	627,000	416,000	329,000	297,000
Contractor Markup and Profit @ 10%	157,000	63,000	42,000	33,000	30,000
Contingency @ 15% ($/year)	259,000	104,000	69,000	54,000	49,000
Total Annual O&M ($/year)	1,983,000	794,000	527,000	416,000	376,000
Total Project O&M (P/W) ($)	1,983,000	2,046,000	2,104,000	2,391,000	2,523,000

needed. If temporary or part-time workers are available, the number of employees may be reduced. For this analysis, only full-time employees are considered.

Total present worth project costs for 1, 3, 5, 8 and 10-year treatment periods are summarized in Table 4-8 and Figure 4-1. Figure 4-1 represents these total costs in terms of cost per ton of soil treated. Significant cost savings are seen by increasing the treatment period from 1 to 3 years. The savings become much less significant with increasing treatment period. Figure 4-1 shows that the costs per ton level off at approximately 3 years treatment time. This curve indicates that relatively small cost savings are achieved by increasing the treatment period beyond 3 years. Within the estimating accuracy in this analysis, the total project costs calculated for 3, 5, 8, and 10-year project durations are indistinguishable.

4.2.3 FACILITY SIZE

As a further study of the effect of remedial project size on project cost, an analysis was conducted to determine the costs associated with processing 2,000 (1,000 tons/year), 5,000 (2,500 tons/year), and 10,000 (5,000 tons/year) tons of soil in a 2-year period. This 2-year treatment period represents a reasonable schedule for an expedited cleanup. As indicated in Subsection 4.2.2, extension of the operating period beyond 3 years offers relatively little economic advantage. Unless otherwise specified, the assumptions used in these calculations are the same as those used in previous subsections.

Table 4-9 presents the estimated capital costs associated with each of the three alternatives. Because of the small facility size required, it is more cost-effective to lease a backhoe and dump truck as needed for the 2,000 (1,000 tons/year) and 5,000-ton (2,500 tons/year) facilities. A backhoe and dump truck would be purchased for the 10,000-ton (5,000 tons/year) option. The facility pad and structure size increase with increasing throughput. Equipment salvage values are not considered.

Table 4-10 presents the estimated annual O&M costs for the three options. Equipment rental costs are included in the 2,000 (1,000 tons/year) and 5,000-ton (2,500 tons/year) options for the 10,000 ton (5,000 tons/year) option, all needed equipment was purchased. Minimal analytics and labor charges have been used. For the purposes of this analysis, only full-time employees have been considered. Cost savings may result if part-time labor is available. The present worth of estimated annual O&M costs was calculated using an 8% annual interest rate.

Total present-worth project costs for the 2,000 (1,000 tons/year), 5,000 (2,500 tons/year), and 10,000-ton (5,000 tons/year) options are presented in Table 4-11. As seen in previous analyses, the cost per ton of soil processed increases with decreasing facility size. The cost per ton of soil is higher than the costs estimated in Subsection 4.2.2.

In this evaluation, the size of the windrow composting facility was varied to achieve the desired soils throughput. For certain of the facility requirements, such as the construction of the composting pad itself, total cost may vary more or less directly with

Table 4-8

Estimated Total Project Costs for Windrow Composting of Varying Project Durations

Project Duration (years)	Soil Treated Per Year (tons)	Capital Cost ($)	Annual O&M ($)	Total Project P/W O&M ($)	Total Project Cost P/W ($)	Cost Per Ton of Soil ($)*
1	20,000	5,330,000	1,983,000	1,983,000	2,313,000	366
3	6,700	2,409,000	794,000	.2,046,000	4,455,000	223
5	4,000	2,118,000	527,000	2,104,000	4,222,000	211
8	2,500	1,931,000	416,000	2,391,000	4,322,000	216
10	2,000	1,753,000	376,000	2,523,000	4,276,000	214

*Assumes 20,000 tons of soil processed.

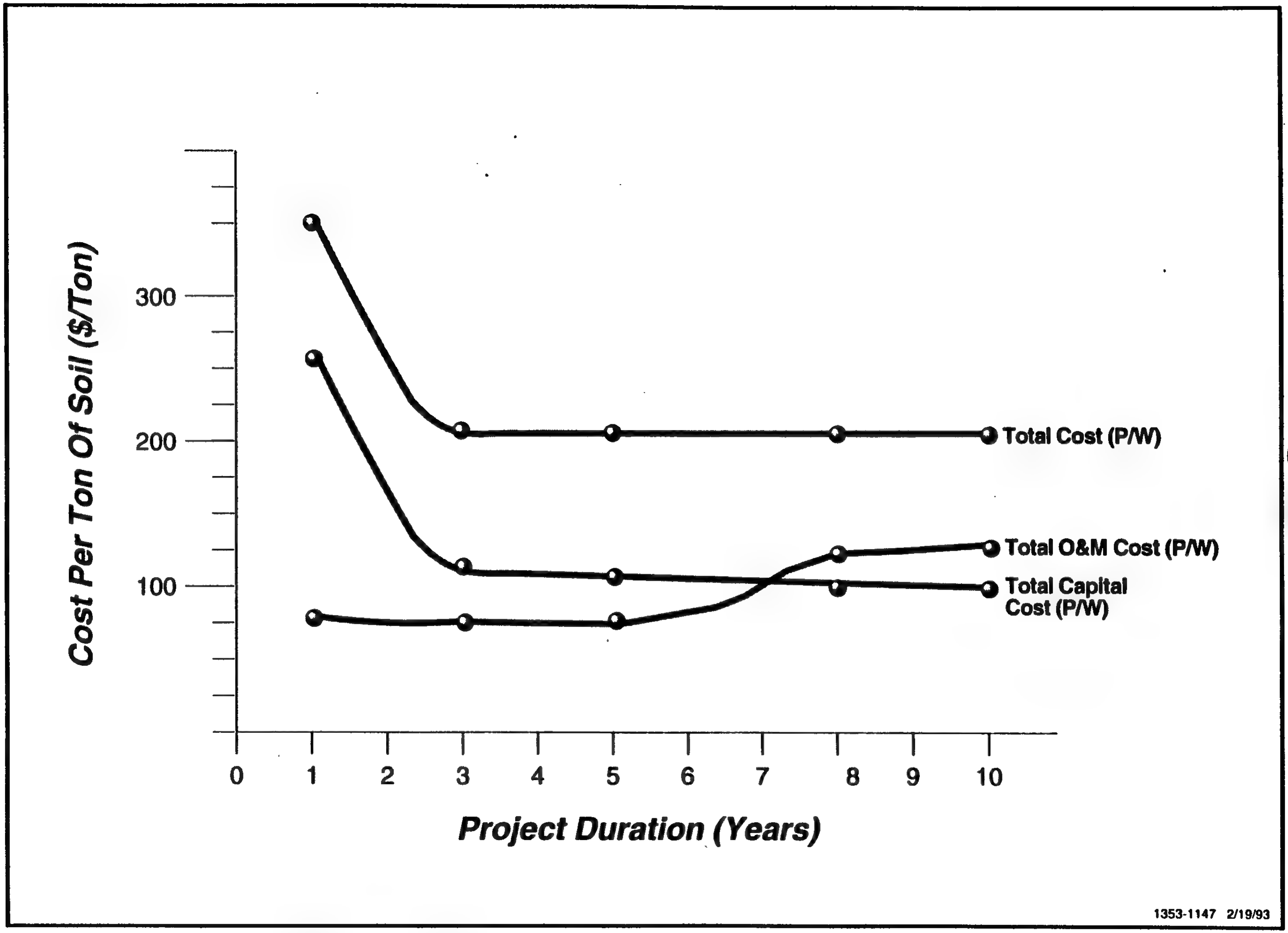

FIGURE 4-1 PROJECT COST PER TON OF SOIL TREATED FOR WINDROW COMPOSTING WITH VARYING PROJECT DURATIONS

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Table 4-9

Estimated Capital Costs for Windrow Composting of Varying Facility Sizes for 2-Year Project Duration

	Tons Treated in 2 Years		
	2,000	5,000	10,000
Equipment ($)	230,000	319,000	634,000
Sitework ($)	92,000	183,000	224,000
Buildings/Structures ($)	155,000	235,000	325,000
Mechanical/Piping ($)	14,000	20,000	35,000
Electrical ($)	64,000	81,000	141,000
First Subtotal Capital ($)	555,000	838,000	1,359,000
Construction Facilities/ Mobilization/Demobilization @ 8% (%)	44,000	67,000	109,000
Consumable Items @ 5% ($)	28,000	42,000	68,000
Fees @ 1.5% ($)	8,000	12,000	20,000
Overhead @ 9.5% ($)	53,000	80,000	129,000
Contractor Markup @ 10% ($)	69,000	104,000	168,000
Contingency @ 15% ($)	114,000	165,000	278,000
Total Capital ($)	871,000	1,266,000	2,131,000

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Table 4-10

Estimated Annual O&M Costs for Windrow Composting of Varying Facility Sizes for 2-Year Project Duration

	Tons Treated in 2 Years		
	2,000	5,000	10,000
Equipment Rental ($)	24,000	24,000	---
Power ($)	1,000	1,000	1,000
Amendments ($/year)	48,000	120,000	241,000
Fuel ($/year)	9,000	11,000	21,000
Labor ($/year)	75,000	108,000	141,000
Analytics ($/year)	21,000	21,000	32,000
Maintenance @ 3% of Capital ($/year)	26,000	37,000	68,000
Subtotal Annual O&M ($/year)	204,000	322,000	504,000
Contractor Markup and Profit @ 10% ($/year)	20,000	32,000	50,000
Contingency @ 15% ($/year)	34,000	53,000	83,000
Total Annual O&M ($/year)	258,000	407,000	637,000
Total Project O&M (P/W) ($)	460,000	726,000	1,136,000

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Table 4-11

Estimated Total Costs for Windrow Composting of Varying Facility Sizes for 2-Year Project Duration

	Tons Treated in 2 Years		
	2,000	5,000	10,000
Capital Cost ($)	871,000	1,266,000	2,131,000
Annual O&M ($)	258,000	402,000	637,000
Total Project P/W O&M ($)	460,000	726,000	1,136,000
Total Project Cost P/W ($)	1,331,000	1,992,000	3,267,000
Cost Per Ton of Soil ($)	666	398	326

the size of the facility (economy of scale in these cost items was not considered in this analysis). Some components, such as the temporary structures, are available in modular form so that reasonably close adjustment of the size to the specific project need is possible. Other components may be available only in fixed sizes and capacities (such as the windrow turner), and the purchase costs for these components may be the same over a wide range of facility sizes. For example, all project sizes up to the maximum capacity of a single windrow turner would incur the same purchase price for this component, and all larger projects would incur a multiple of this price, depending upon the number of such machines required. To some extent, this unit price effect is disadvantageous for small project sizes that do not fully use the capacity of such equipment. One option to minimize this effect would be to lease such equipment for small projects where technically feasible and economically advantageous.

To some extent this effect may also be seen in operating costs, particularly in operating labor. While certain labor tasks may be amenable to the use of part-time labor, it is likely that a minimal full-time staff may be required, particularly in light of the technical requirements for hazardous waste work and what may be somewhat remote project locations.

In this sensitivity evaluation, as with those presented previously, costs for various size projects were developed by varying capital and operating requirements from the baseline developed in Subsections 4.1.1 and 4.1.2 to provide a comparison among remedial project sizes. Costs for each specific project size were not fully optimized by detailed design analysis for purposes of this cost comparison.

4.3 ALTERNATIVE COMPOSTING SYSTEMS

This section will discuss composting using the aerated static pile and mechanical in-vessel systems. This analysis is based upon the previous technology development study [3] and information obtained in the composting optimization field study [4]. In both cases, brief descriptions of system operation and economics are presented.

4.3.1 AERATED STATIC PILE COMPOSTING

The aerated static pile system considered for this analysis is based on a rectangular bin configuration (three wooden walls) with dimensions of 60 ft long by 40 ft wide by 8 ft high (711 yd^3) [3]. For bins of this size, three operating pads (with a fourth inactive pad) would be needed to process 20,000 tons of soil in 5 years (4,000 tons/year). The compost mixture considered would be the same as that described in Section 3. The treatment period of 60 days selected was based on results of the UMDA field study [5]. Although several aerated static pile trials in the UMDA studies [4, 5] achieved the targeted 99.5% removal of TNT, this goal was not consistently met in the 40-day composting period. Therefore, to ensure treatment to the targeted level, a 60-day composting period was assumed. As with the windrow system, a RCRA facility was assumed. A description of potential RCRA requirements is presented in Appendix B. A cross-section of a typical aerated static pile system is shown in Figure 4-2.

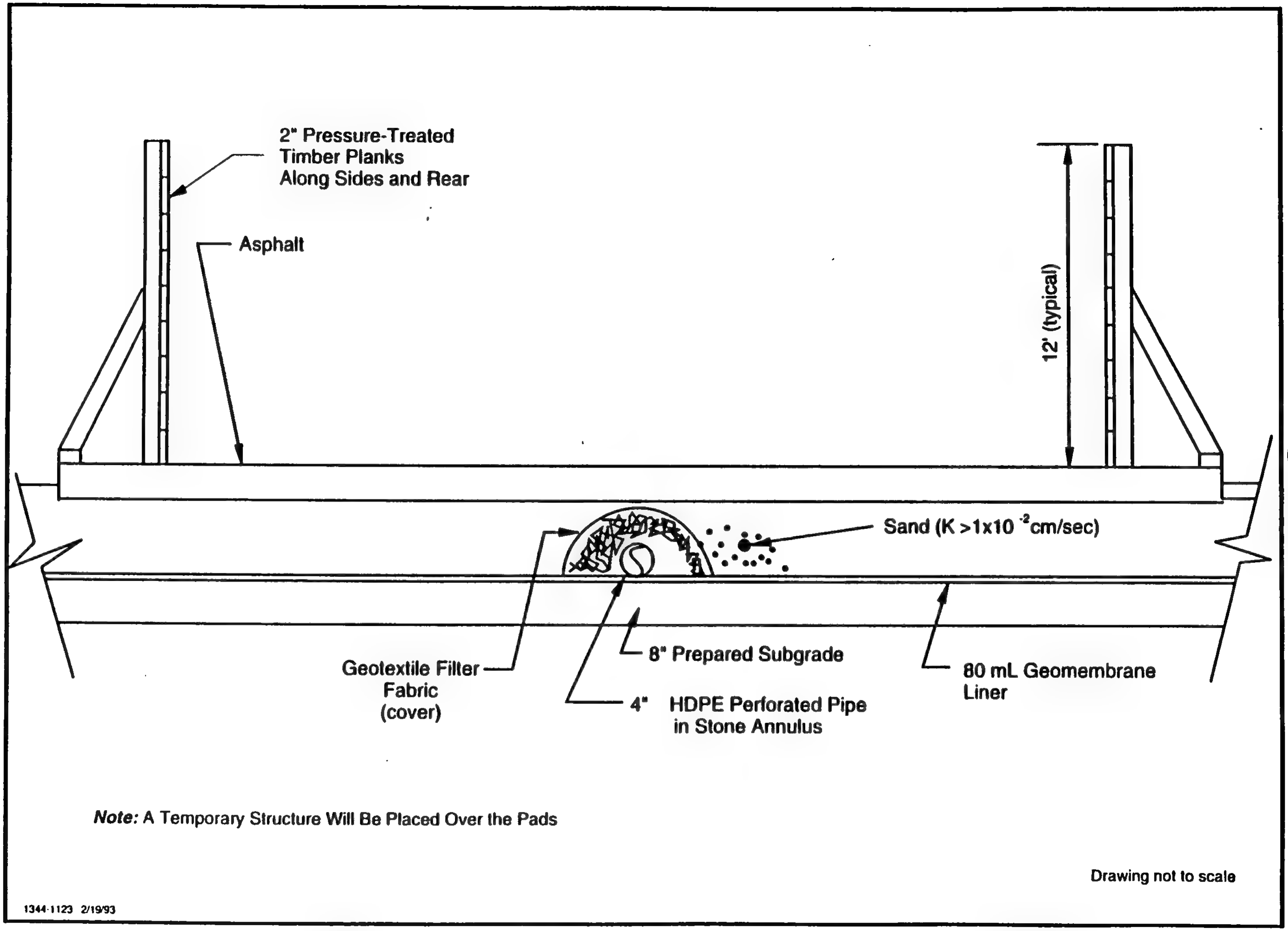

FIGURE 4-2 CROSS-SECTION OF TYPICAL AERATED STATIC PILE AND BIN

An equipment list for the aerated static pile system is presented in Table 4-12. The windrow turner found in the windrow composting system description is not needed for aerated static pile composting and has been eliminated for this analysis. An alfalfa tub grinder (used to debale and chop the straw and alfalfa) and compost mixer (a batch mixer to blend the amendments and soil) have been added. These pieces of equipment were used in the aerated static pile system in the previous engineering study [3]. Design and costing assumptions for this analysis are consistent with those described for the windrow composting system. Excavation and backfilling costs are included on an annual basis. Equipment for these efforts as well as covering the finished compost in the backfill area are included as capital costs. O&M unit costs are the same as those presented in Table 4-3 for the windrow composting system. The same assumptions and methods described in Subsections 4.1.2.1 and 4.1.3 have been used in calculating present worth and salvage values.

The facility would be covered with a portable structure (approximately 200 ft by 75 ft), such as a clamshell structure to prevent runon to the system. The amendments would be staged on asphalt and the excavated soils would be staged in the dump truck.

Several changes in assumptions have been made in this analysis compared to the previous engineering study [3]. These changes have been based on experience gained [4, 5] since the publication of the previous study. The assumption changes are:

- The design basis for the composting system has been set at 20,000 tons of soil to be processed in 5 years (4,000 tons/year) in keeping with the facility size used in the windrow composting system.
- A 30 volume percent soil compost mixture is used in the current study compared to a 10 volume percent soil mixture in the previous study. This change allows for an increased throughput for a given facility size.
- The straw/manure and alfalfa amendment mixture from the previous study was replaced with the straw/alfalfa, potato waste, and manure mixture developed during the UMDA field demonstrations [4, 5].
- The compost cycle time of 90 days used in the previous study has been changed to 60 days, based on observed TNT removal during the UMDA field demonstrations [4, 5].
- A temporary structure has been added to control runon and precipitation to the site.
- The pad used for composting is now an asphalt pad as opposed to a reinforced concrete pad. The liner and leak detection system have been retained. This assumption is consistent with those used in the windrow composting system and complies with current RCRA regulations.

Table 4-12

Major Equipment List for Aerated Static Pile System

Equipment	Quantity
1 yd^3 Backhoe	1
12 yd^3 Dump Truck	1
Alfalfa Tub Grinder	1
2 yd^3 Front-End Loader	2
Batch Mixer	1
30-hp Blowers	4
10-gpm Water Pump (for sump)	1

- The aeration trenches in the composting pad from the previous study have been eliminated. The aeration pipes will be placed on top of the asphalt pad in a bed of wood chips.

- Compost final disposal costs were not included in the previous study but have been included in this analysis, as on-site backfill and cover.

- No contingency was added in the previous study. In keeping with the assumptions made in the windrow study, a 15% contingency was used in this analysis.

4.3.1.1 Aerated Static Pile Costs

Capital costs for the aerated static pile composting system are presented in Table 4-13. With the exception of the equipment changes described in Subsection 4.3, the items included in the capital costs are the same as those presented in Table 4-1 for the windrow composting system. A 15% contingency was added to the capital costs.

Annual O&M costs for the aerated static pile composting system are presented in Table 4-14. A 15% contingency was added to the annual costs. The present worth of a 5-year project was calculated assuming an 8% annual interest rate.

As with the windrow composting analysis, much of the equipment used in the aerated static pile system is assumed to have a 10-year useful life. The straight-line depreciation method was used to determine the salvage value of the temporary structure, backhoe, dump truck, front-end loader, alfalfa tub grinder, and batch mixer at the end of the 5-year project life. Total project cost with and without salvage values are presented in Table 4-15. The total 5-year project cost without salvage is estimated to be $5,659,000, or $283 per ton of soil treated. Accounting for salvage values lowers the 5-year present worth project cost to $5,431,000 or $272 per ton of soil treated.

This system is sized to treat 20,000 tons of soil in 5 years, or 4,000 tons of soil per year. For comparison, in the previous engineering study [3], the comparable size aerated static pile system processed 3,600 tons of soil per year. The previous study presented a 5-year present worth total project cost of $6,067,000 or $337 per ton of soil treated for this system.

The difference in cost between the two analyses is a result of the assumption changes discussed in Subsection 4.3.1.

4.3.2 MECHANICALLY AGITATED IN-VESSEL COMPOSTING

For purposes of comparison, a mechanical composting system was also considered. In keeping with the previous Engineering Study [3], the Fairfield digester unit was chosen. This is the only mechanical system for which performance data are available; however, other mechanical systems may also prove suitable. A 30 volume percent soil compost mixture using the amendment mixture from Section 3 was assumed. Based on the

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Table 4-13

Estimated Capital Costs for Aerated Static Pile Composting System

	Cost ($)
Equipment	561,000
Site Work	268,000
Structures	323,000
Mechanical/Piping	36,000
Electrical	195,000
First Subtotal Capital	1,383,000
Project Construction Facilities/Mobilization/ Demobilization @ 8%	111,000
Construction Equipment Consumable items @ 5%	69,000
Permits and Fees @ 1.5%	20,000
Subtotal Capital	**1,583,000**
General and Administrative Overhead @ 9.5%	150,000
Contractor Markup and Profit @ 10%	174,000
Contingency @ 15%	286,000
Total Capital	**2,193,000**

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Table 4-14

Estimated Annual O&M Costs for Aerated Static Pile Composting System

	Cost ($)
Power	8,000
Amendments	195,000
Wood Chips	138,000
Diesel Fuel	14,000
Labor	166,000
Maintenance	66,000
Analytics (off-site)	99,000
Subtotal Annual O&M	**686,000**
Contractor Markup and Profit @ 10%	69,000
Contingency @ 15%	113,000
Total Annual O&M	868,000
Total 5-Year O&M (Present Worth)	**3,466,000**

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Table 4-15

Total Estimated 5-Year Project Cost for Aerated Static Pile Composting System

	Cost ($)
Without Salvage Values	
Total Capital	2,193,000
Total 5-Year O&M (P/W)	3,466,000
Total 5-Year Project cost (P/W)	5,659,000
Soil Treated in 5 Years (Tons)	20,000
Cost Per Ton of Soil	283
Including Salvage Values	
Total Capital (Including Salvage)	1,965,000
Total 5-Year O&M (P/W)	3,406,000
Total 5-Year Project cost (P/W)	5,431,000
Soil Treated in 5 Years (Tons)	20,000
Cost Per Ton of Soil	272

results of the UMDA study [4], a 30-day retention time was chosen. The amendments will be staged on a pad and the soils will be staged in the dump truck. The compost will be prepared and mixed initially with a batch mixer prior to entering the system.

The MAIV composting facility centers on the Fairfield digester unit. A typical MAIV system is shown in Figure 4-3. According to vendor information [16], the cost of the unit would include the reactor itself, the associated mechanical equipment, a concrete foundation, and installation. A reactor diameter of 78 ft was chosen from the sizes provided by the vendor. Although the reactor size would be optimized during actual system design, this provides an approximation of equipment size and costs. Materials preparation and handling equipment such as that found in the aerated static pile composting system are also needed. This equipment includes a backhoe, front-end loader, dump truck, batch mixer, alfalfa tub grinder.

Excavation and redisposal costs associated with labor and fuel changes are included on an annual basis. Equipment for these efforts as well as covering of the compost in the excavation area are included in the capital costs.

O&M unit costs are the same as those presented in Table 4-3 for the windrow composting system. Equipment power requirements were provided by the vendor [16]. Equivalent assumptions and methods described in Subsection 4.1.2.1 have been used in calculating present worth.

4.3.2.1 Mechanically Agitated In-Vessel Composting System Cost

The assumption changes in this analysis as compared to the MAIV analysis in the previous engineering study [3] are as follows:

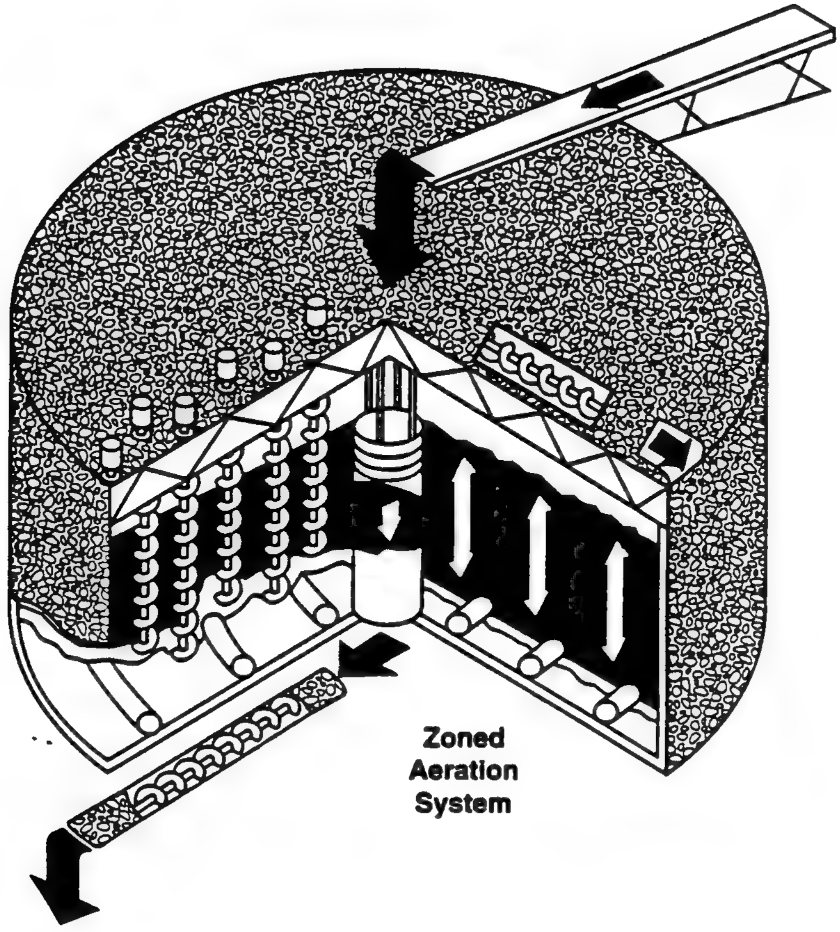
- A 30 volume percent soil compost mixture is used in the current study. Soil volume fractions of 10, 25, and 40% were tested in the previous study. This change allows direct comparison of the three systems described in this study.

- As with the aerated static pile system, the amendment mixture was changed to reflect the mixture developed during the UMDA field demonstrations [5].

- A compost cycle time of 30 days was assumed based on observed TNT removal in the UMDA field demonstration [4]. This retention is significantly longer than the 14-days assumed in the previous study.

- Finished compost disposal costs were not included in the previous study, but have been included in this analysis as on-site backfill.

Mechanically Agitated In-Vessel System



Source: Fairfield Service Co.

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FIGURE 4-3 TYPICAL MECHANICALLY AGITATED IN-VESSEL COMPOSTING REACTOR

The capital costs associated with the MAIV composting system are presented in Table 4-16. Equipment costs include a backhoe, dump truck, front-end loader, batch mixer, and alfalfa tub grinder. The sitework costs include the costs associated with preparing the site (clearing and grubbing, grading) as well as the costs for covering the finished compost in the excavation area.

The reactor costs include the reactor itself, mechanical equipment, and the reactor concrete foundation. Any sitework specifically associated with the reactor installation are assumed to be included in the reactor cost. The mechanical/piping costs account for site drainage and storm run-off control. Finally, the electrical costs include equipment power distribution and site lighting.

Annual O&M costs for the MAIV system are presented in Table 4-17. A 15% contingency was added to the annual costs. The present worth of a 5-year project was calculated assuming an 8% annual interest rate.

As with the windrow and aerated static pile composting systems, much of the equipment used in the MAIV composting system is expected to have a portion of its useful life remaining at the end of the 5-year project. In keeping with the assumptions used in the other composting systems in this study, a 10-year useful life was assumed for the backhoe, front-end loader, dump truck, batch mixer, and alfalfa tub grinder. A straight-line depreciation method was used to determine the worth of these items at the end of the 5-year project. Based on vendor information [16], the reactor was treated separately. The reactor and associated mechanical equipment is assumed to have a 20-year useful life. Approximately 50% of the reactor capital costs (before depreciation) may be considered for salvage cost calculations if the equipment is to be used for another composting project. If the equipment must be sold to an outside source, only about 5% of the capital costs (before depreciation) are salvageable [16]. Assuming that the salvaged equipment may be used at another remediation site, a salvage value was calculated for the MAIV reactor. Fifty percent of the capital investment for the reactor was straight-line depreciated over a projected 20-year useful life. Table 4-18 presents total 5-year present worth project costs with and without salvage values. Without accounting for salvage values, the total 5-year present worth cost is $6,280,000, or $314 per ton of soil treated. If salvage values are considered, the total 5-year present worth cost is $5,969,000 or $298 per ton of soil treated.

The costs developed in the previous engineering study [3] are not directly comparable to the costs presented here as different soil volume fractions and retention times were used. Table 4-19 presents a summary of the total project costs and costs per ton of soil treated which were determined in the previous study. Given the previously discussed differences in assumptions between the two studies, costs developed in this study appear to be somewhat less than those presented in the previous study. Again, changes in assumptions can account for these differences.

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Table 4-16

Estimated Capital Costs for MAIV Composting System

	Cost ($)
Equipment	510,000
Site Work	138,000
Reactor	1,367,000
Mechanical/Piping	4,000
Electrical	201,000
First Subtotal Capital	**2,220,000**
Project Construction Facilities/Mobilization/ Demobilization @ 8%	178,000
Construction Equipment Consumable items @ 5%	111,000
Permits and Fees @ 1.5%	33,000
Second Subtotal Capital	**2,542,000**
General and Administrative Overhead @ 9.5%	242,000
Contractor Markup and Profit @ 10%	278,000
Contingency @ 15%	450,000
Total Capital	**3,512,000**

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Table 4-17

Estimated O&M Costs for MAIV Composting System

	Cost ($)
Power	51,000
Amendments	195,000
Wood Chips	0
Diesel Fuel	17,000
Labor	154,000
Analytics (off-site)	23,000
Maintenance	106,000
First Subtotal Annual O&M	**546,000**
Contractor Markup and Profit @ 10%	55,000
Contingency @ 15%	90,000
Total Annual O&M	691,000
Total 5-Year O&M (Present Worth)	**2,759,000**

Table 4-18

Total Estimated 5-Year Project Cost for MAIV Composting System

	Cost ($)
Without Salvage Values	
Total Capital	3,521,000
Total 5-Year O&M (P/W)	2,759,000
Total 5-Year Project cost (P/W)	6,280,000
Soil Treated in 5 Years (Tons)	20,000
Cost Per Ton of Soil	314
Including Salvage Values	
Total Capital (Including Salvage)	3,210,000
Total 5-Year O&M (P/W)	2,759,000
Total 5-Year Project cost (P/W)	5,969,000
Soil Treated in 5 Years (Tons)	20,000
Cost Per Ton of Soil	298

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Table 4-19

Total Present-Worth Project Cost for MAIV Composting in Previous Engineering Study [3]

Retention Time (days)	Soil Fraction	Capital Costs ($)	Tons Treated in 5 Years	Cost Per Ton ($)
14	20	6,313,000	23,000	274
14	40	6,122,000	45,000	136
90	40	5,200,000	4,000	1,300
90	40	5,170,000	7,000	739

4.4 COMPARISON OF TREATMENT ALTERNATIVES

This study has presented economic analyses for windrow, aerated static pile, and mechanically agitated in-vessel (MAIV) composting systems. All systems were sized to process 20,000 tons of explosives-contaminated soils in a 5-year treatment period. An initial compost mixture of 30 volume percent soils is assumed in all cases. Cycle times for each system were determined based on previous composting experience [4, 5].

An alternative technology that could be used in the treatment of explosives-contaminated soils is incineration. Previous WESTON experience [19] shows an on-site incineration remediation to have a mobilization/demobilization cost of approximately $2,000,000. The additional processing cost is then approximately $200 per ton of soil treated. These costs are for treatment only and do not reflect excavation and final disposal costs. Using a basis of 20,000 tons of soil treated, this would mean a total project cost of $6,000,000, or $300 per ton of soil. This cost includes mobilization/demobilization of the incinerator, but does not include excavation or compost redisposal.

Therefore, in order to evaluate the costs associated with using composting technology versus other incinerator remediation technologies, a "treatment only" cost was calculated. These costs, presented in Table 4-20, differ from those presented in previous sections in that they do not include excavation and final compost disposal charges. Incineration treatment costs are presented for comparison with the three composting alternatives. MAIV composting shows a slight cost savings over incineration. More significant savings are seen for aerated static pile and windrow composting.

Figure 4-4 [20] illustrates a range of incineration costs associated with various remedial project sizes. For the project size described in this report, all fall in the lower range of costs for similarly sized incineration projects.

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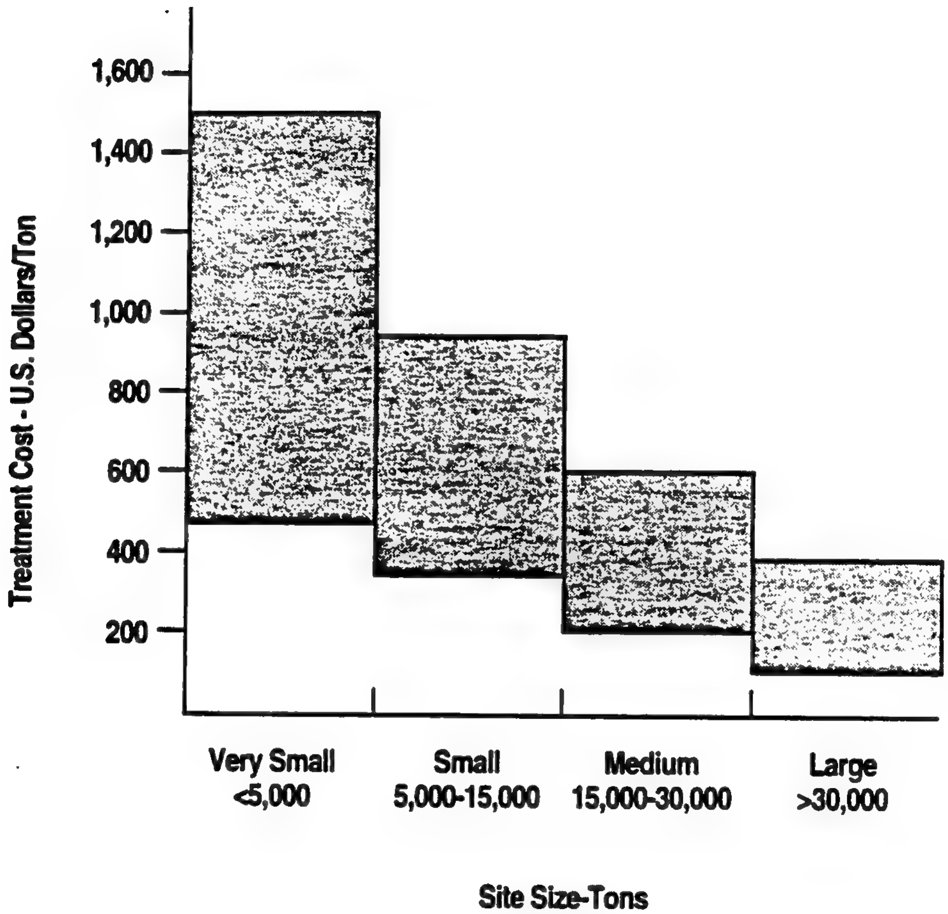
Table 4-20

Estimated "Treatment Only"[a]
Project Costs for Composting and Incineration

Technology	Capital Cost ($)[b]	Annual O&M Cost ($)	5-Year O&M Cost ($)	Total Project Cost ($)	Cost per Ton ($)[c]
Windrow Composting	1,891,000	464,000	1,853,000	3,744,000	187
Aerated Static Pile Composting	1,966,000	692,000	2,763,000	4,729,000	236
MAIV Composting	3,294,000	628,000	2,507,000	5,801,000	290
Incineration	2,000,000[d]	u[e]	4,000,000[f]	6,000,000	300

[a]Costs do not include excavation and final disposal.
[b]Based on 20,000 tons of soil processed.
[c]Does not include salvage values of equipment.
[d]Mobilization/Demobilization only.
[e]Annual costs are not determined; 5-year total based upon net cost per ton is provided.
[f]Based on 20,000 tons of soil @ $200/ton.



Source: The Hazardous Waste Consultant

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FIGURE 4-4 EFFECT OF SITE SIZE ON INCINERATION COSTS

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to evaluate economics for using windrow composting technology remediation of explosives-contaminated soil at various Army ammunition plants (AAPs) and Army depots (ADs). This included the development of a conceptual design and operating requirements and an economic evaluation of the potential costs associated with facility construction and operation. The process development was based largely on previous work conducted by USAEC at LAAP [1], BAAP [2], and UMDA [4,5]. Capital and O&M cost estimates were based on conventional construction estimating practices in conjunction with experience gained during the UMDA field demonstrations [4].

As shown in Table 4-20, the results of this economic evaluation show that windrow composting treatment costs are less than aerated static pile or mechanical composting. The MAIV composting system is comparable on a cost-per-ton basis to incineration at $290 per ton of soil treated compared to $300 per ton for incineration. The greatest cost savings in comparison to incineration are seen by the windrow composting system at $187 per ton. The aerated static pile system "treatment only" costs are estimated at $236 per ton. All estimates were based on treating 20,000 tons of soil in a 5-year period. If the amount of soil or treatment time were varied, the costs would be altered.

In addition to the cost savings demonstrated by windrow composting in comparison to other composting methods, there are other, less quantifiable, advantages associated with the use of a windrow system. For example, the windrow system has significantly less process control requirements, and so has less equipment subject to downtime that could lead to system performance variations. Also, the windrow system has demonstrated RDX (99.8% removal) and HMX (96.8% removal) reduction [5] The other composting systems have not shown this level of destruction. Table 5-1 presents percent reductions of TNT, RDX and HMX for windrow, aerated static pile, and MAIV composting systems. These data were obtained from UMDA composting field demonstrations [4, 5]. Note that the MAIV data presented are for 25 volume percent soil because data at 30 volume percent is not available. If RDX or HMX removal is necessary, longer treatment periods than those presented in this study may be needed for the aerated static pile and MAIV composting systems. Because this increased removal of RDX and HMX has not been demonstrated, the required composting period for a given percent explosives reduction would need to be determined through further testing if aerated static pile or MAIV composting is used.

Based on the results presented in this study and past field demonstrations, it is recommended that the use of windrow composting be pursued and developed further for possible use in remediation of explosives-contaminated soil. Although all of the basic research and development needed for implementation has been completed, several areas that could possibly be optimized with further testing. These include:

Table 5-1

Demonstrated Percent Reduction of Explosives for Various Composting Technologies

Technology	% Reduction		
	TNT	RDX	HMX
Windrow	99.7	99.8	96.8
Aerated Static Pile	99.7	93.7	61.8
MAIV	99.5	85.1	50.0

- The compost treatment time could be reduced from the 30-day baseline case. Tests would be needed to confirm system performance at shorter times.

- The soil volume fraction in the compost mixture could be increased. Although the process appears to be economically viable at 30% soil loadings, tests could be conducted to find if the higher soil fraction can be successfully composted in windrows.

- Regulatory requirements that govern the composting facility should continue to be monitored. If it is found that RCRA facilities minimum technology design standards are not required, cost savings of approximately $5 per ton are possible. Additionally, the burden of regulatory approval may be eased substantially.

SECTION 6

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APPENDIX A

SUMMARY OF AVAILABLE WINDROW COMPOST TURNERS

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Table A-1

Summary of Available Windrow Compost Turners

Manufacturer	Model	Belt/Hydraulic Drive	Flail/ Flight	Typical Windrow Size
A-1 Environmental	Sims 2000	Hydraulic	Flail	12-14 ft wide 5-6 ft high
Brown Bear Corporation	500	Hydraulic	Auger	12 ft wide 4 ft high
Eagle Crusher Co.	Straddle Master II	Hydraulic	Flail	14 ft wide 4-6 ft high
	Straddle Master II	Belt	Flail	14 ft wide 4-6 ft high
Resource Recovery Systems of Nebraska	KW614	Hydraulic	Flail	14 ft wide 6 ft high
	KW614	Hydraulic	Flail	14 ft wide 6 ft high
Scarab Manufacturing	Model 14	Belt	Flail	14 ft wide 6 ft high
	Model 14	Hydraulic	Flail	14 ft wide 6 ft high
Valoraction, Inc.	Sittler 1012	N/A	Flail	10-12 ft wide 4'8" high
Wildcat Manufacturing	CM750-AME-SPECIAL	N/A	Flail	17 ft wide 5 ft high

Note: An explosive hazard analysis has been performed for the KW614 (used in the UMDA field demonstration [5]). This analysis would be required if any of the windrow turners were used.

APPENDIX B

REGULATORY ISSUES

APPENDIX B

REGULATORY ISSUES

The sediments resulting from or soils contaminated with the accumulation of pink water from explosives manufacturing and washout operations are classified as a listed hazardous waste from specific sources — K047 (pink/red water from TNT operations) as defined in 40 CFR 261.32. The RCRA classification of contaminated sediments should be reviewed on a site-specific basis for final determination. If these soils are to be composted in a windrow or aerated static pile system, the soils are mixed with amendments and formed into piles. These piles may be considered to be waste piles from a regulatory viewpoint.

As defined in 40 CFR 260.10, "pile" means any noncontaminated accumulation of solid, nonflowing hazardous waste that is used for treatment or storage. On the basis of this definition, Subpart L regulations appear to apply to composting. Under Subpart L of 40 CFR 264, the treatment facility (waste pile) must meet RCRA facility design requirements. These requirements include a double liner system and a leachate collection system. These requirements, however, may be waived at the Regional Administrator's discretion (40 CFR 264, Subpart L).

Additionally, 40 CFR Subpart F regulates the groundwater monitoring requirements for treatment facilities that treat hazardous waste in piles. Exemptions from the Subpart F monitoring requirements may be possible if it is demonstrated that neither runoff nor leachate is generated from the pile. Specifically, the following should be demonstrated during construction of the compost piles (40 CFR 264.250(c)):

- Protection from precipitation — Demonstrate that the pile is inside or under a structure that provides complete protection from precipitation.
- Free liquids — Demonstrate that neither liquids nor materials are placed in the pile.
- Runon protection — Demonstrate that the pile is protected from surface water runon by the structure or in some other manner.

- Wind dispersal control — Demonstrate how the pile design and operation controls wind dispersal of wastes.

- Leachate generation — Demonstrate that the pile will not generate leachate through decomposition or other reactions.

After evaluation of these factors, it is possible that the composting system would be exempted by the Regional Administrator from the requirements of a liner system, a leachate collection system, and 40 CFR 264 Subpart F monitoring requirements.

Additional standards that may warrant investigation on a case-specific basis include:

- RCRA facility closure requirements applying after the facility ceases operation.

- State RCRA requirements (where approved by EPA) may be more stringent than federal standards.

- State solid waste regulations, if the soils are determined to be nonhazardous.

- Local erosion and sedimentation (E&S) plan requirements for facility construction and operation.